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AC-4 ATLAS-CENTAUR FLIGHT EVALUATION (LAUNCHED DECEMBER 11, 1964)

by the Staff of the
Lewis Research Center
Cleveland, Ohio

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SECTION 1. SUMMARY

15063 ABST

The AC-4 Atlas-Centaur launch vehicle (Atlas 146D, Centaur 4C), including a Surveyor Mass Model of 2100 pounds, was successfully launched from ETR Complex 36A at 0925:02 EST on December 11, 1964. The primary test objectives of the AC-4 flight were satisfied.

The AC-4 launch vehicle was launched on an azimuth of 105 degrees East of true North and was programmed to a flight azimuth of 102.5 degrees East of true North. The first burn of Centaur main engines injected the Centaur 4C and the Surveyor Mass Model into a near perfect 90 NM circular orbit (94.92 NM apogee altitude, 88.20 NM perigee altitude). First look at data indicates a near nominal flight path indicating that the closed-loop guidance system functioned properly. This was the initial attempt to employ such a guidance system.

The AC-4 launch vehicle was the first in the Centaur series with restart capabilities. Centaur main engine restart (secondary objective) was programmed to take place after an approximate 15 minute coast period in the nominal 90 NM circular orbit; however, restart of the main engines did not occur due to tumbling of the Centaur; tumbling started at about MECO + 4.50 minutes. Although second burn was not achieved, the guidance system continued to function properly to the end of the programmed flight. An attempt to recover the nose fairing was made but neither the nose fairing nor insulation panels were recovered.

The launch day countdown commenced at 3 A.M. EST on December 11 and proceeded normally until T-90 minutes. During the 1 hour built-in hold at T-90 minutes, a regulator problem developed in the launcher stabilization

system and a 1/4 second power drop-out was observed to the vehicle. The 1 hour hold was extended for 35 minutes at which time the count was picked up and proceeded normally to lift-off. The 10 minute built-in hold at T-5 minutes was not used.

SECTION 2. INTRODUCTION

The AC-4 Centaur successfully launched into a near Earth orbit Dec. 11, 1964 from the Eastern Test Range, was the fourth in a series of development flights. Ultimately the Atlas-Centaur vehicle is to be used to place a Surveyer payload on the Moon. The subject test was the first in which a mock payload of 2100 pounds was carried aboard the vehicle. Objectives of the flight are enumerated below.

Primary Test Objectives

1. Demonstrate the structural integrity of the Atlas and Centaur vehicle during all phases of flight
2. Demonstrate the system integrity of the Guidance System
3. Obtain data on the measuring accuracy of the Guidance System during closed loop flight
4. Demonstrate that the Guidance System provides proper discrete and steering signals to Atlas and Centaur flight control systems
5. Verify the structural and thermal integrity of the Centaur nose fairings and insulations panels
6. Verify the satisfactory performance of the insulation panel and nose fairing jettison system

Secondary Test Objectives

1. Obtain data on the performance of the Centaur's main engine system
2. Demonstrate the restart capabilities of the Centaur main engine system in flight environment
3. Obtain data on the following flight environments: Pressures, temperatures, and vibration levels

4. Verify the satisfactory operation of the Atlas/Centaur separation system
5. Verify that the flight control system supplies proper signal for attitude control and dynamic stability of the Centaur vehicle
6. Demonstrate the capabilities of the coast motors and attitude control system to retain the propellants in the proper attitude for engine restart
7. Obtain data on the vehicle acceleration, propellant behavior and heat transfer, and propellant tank ullage temperatures and pressure histories during coast phase
8. Obtain data on the performance of the H_2O_2 system, hydraulic system, pneumatic system, electrical system and RF systems (telemetry, Azusa and C-band beacon.)
9. Obtain data on the performance of all of the Atlas systems
10. Obtain data on the launch-on-time capability (fixed launch azimuth) of the Atlas/Centaur
11. Demonstrate that the Guidance equations and the associated trajectory parameters are satisfactory
12. Obtain data on the capability of the Centaur to perform a retro-maneuver
13. Obtain data on the spacecraft environment during the launch-to-spacecraft separation phase of flight
14. Verify the ability of the Centaur propulsion system to start in the flight environment and burn to Guidance cutoff
15. Obtain data on the orbital environments, terminal behavior, and general post-mission performance of vehicle systems until loss of all data links

TABLE 2-1. - Concluded

SEQUENCE OF FLIGHT EVENTS*

Event	Nominal time	Actual time
Ullage control engines on	T+573	
Admit guidance for attitude cont.	T+573	
H_2O_2 separate on	T+583	
Open LH_2 vent valve	T+615	T+614.8
No. 1 vent valve relieved	-----	T+840
Close LH_2 vent valve	T+2006.0	
Start boost pumps	T+2010.0	
LO_2 prestart	T+2045.0	
LH_2 prestart	T+2045.0	
2nd Mes	T+2050.66	
Ullage control engines off		
Inhibit guidance		
Admit guidance for steering		
2nd MECO	T+2104.66	
Inhibit guidance		
Admit vector number 2		
H_2O_2 separate on		
Simulate spacecraft separation		
Admit guidance (begin reorientation)	T+2158.16	
LO_2 prestart (end reorientation, begin retromaneuver)		
LH_2 prestart		
H_2O_2 All off (end retromaneuver)	T+3520.16	
Open LH_2 vent valve		
Open LO_2 vent valve		
Energize power changeover switch		

*Times are preliminary and subject to change.

A listing of the flight events are presented in Table 2-1. A schematic diagram of the AC-4 flight is shown in Figure 2-1. General arrangement of the Centaur stage is indicated in Figure 2-2. The purpose of the present paper is to summarize the AC-4 flight results from a preliminary examination of the available data.

TABLE 2-1

SEQUENCE OF FLIGHT EVENTS*

Event	Nominal time	Actual time
Guidance go inertial	T-8	T-7.6
Lock LH_2 vent valve	T-8	T-6.9±0.5
Two-inch motion	T+0	T+0
Start roll program	T+4	T+4
Start pitch program	T+15	T+15.4
Number 2 LH_2 vent valve relieved	----	T+60.5
Open LH_2 vent valve	T+74	T+73.96±0.5
Enable booster staging	T+145	
Close LH_2 vent valve	T+148	T+148.58±0.5
BECO discrete	T+150.04	T+148.81
Jettison booster package	T+153.04	T+151.89
Open LH_2 vent valve	T+158.0	T+158.85±0.5
Jettison insulation panels	T+200.01	T+198.47
Start Centaur boost pumps	T+209.1	T+207.5
Unlatch nose fairings	T+213.6	T+211.89
Jettison nose fairing	T+214.04	T+212.39
Enable SECO	T+220.1	
SECO	T+226.04	T+224.33
VECO	T+226.04	T+224.33
Close LO_2 vent valve	T+226.2	
Close LH_2 vent valve	T+226.2	T+224
Start hydraulic recirculating pump		
Pressurize LO_2 tank (BURP)	T+226.3	T+224.3
Pressurize LH_2 tank (BURP)	T+226.3	T+224.3
Atlas/Centaur separation	T+228.64	T+226.68
Fire Retro rockets	T+228.7	T+226.9
LO_2 prestart	T+229.7	T+227.94
LH_2 prestart	T+229.7	T+227.94
Enable guidance for attitude control		
Main engine start 1st	T+235.64	T+233.87
Enable guidance for steering	T+239.7	T+237.9
Main engine cutoff (MECO)	T+573.66	T+572.76

*Times are preliminary and subject to change.

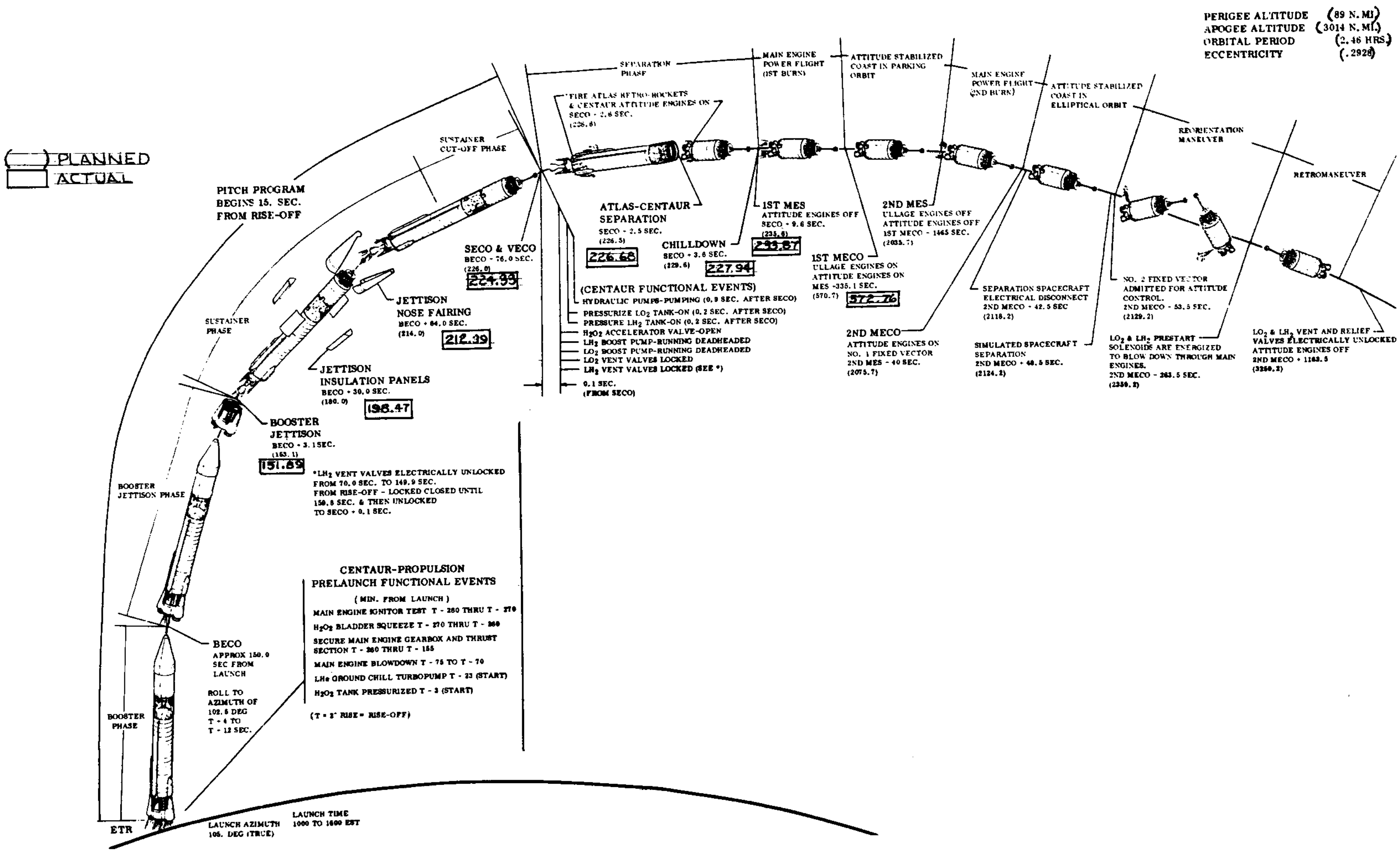


Fig. 2-1 AC-4 FLIGHT COMPENDIUM

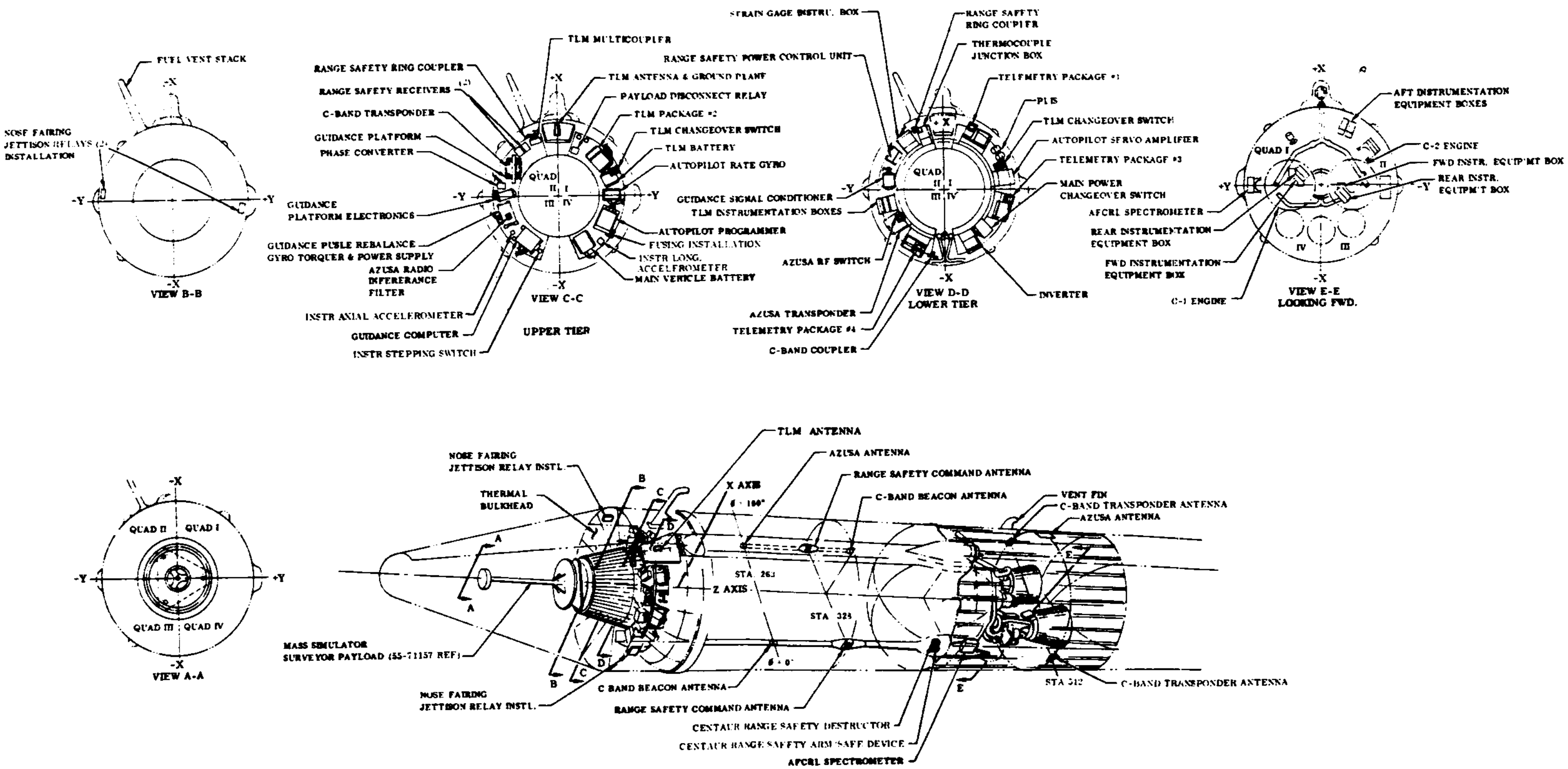


Fig. 2-2 CENTAUR 4C GENERAL ARRANGEMENT

SECTION 3. LAUNCH OPERATIONS

PRELAUNCH HISTORY

The atlas booster 146D arrived at ETR on July 23 followed by the Interstage Adapter (I/A) on July 28. On July 30 the booster was erected on Complex 36A followed by the I/A on August 4. The Centaur 4C arrived at ETR on August 14 and erected and mated to Atlas on August 20.

The Atlas/Centaur launch vehicle was de-erected on September 8 due to Hurricane Dora approaching the coast of Florida. The vehicle was re-erected starting with Atlas 146D on September 14, I/A on September 15 and Centaur 4C on September 16.

The first A/P and Guidance Intergrated Test was conducted on October 16. The test was completed, but due to a discrepancy that occurred, the Centaur programmer was sent to San Diego for rework. The problem involved a resistor of the wrong value in the timing circuit. Due to this resistor the 10 second duration of the reorientation vector enabled at retromaneuver was not accomplished. The second A/P and Guidance Intergrated Test was conducted on October 22. The test was completed and all results were satisfactory.

The first Flight Control and Propellant Tanking Test was conducted on October 27. The test was terminated due to the overpressurization of the Centaur LO_2 tank. The overpressurization was due to a failure in the Propellant Level Indicating System (PLIS) and the failure to acknowledge the 100 percent propellant level indicator light. Prior to the second Flight Control and Propellant Tanking Test conducted on November 6, a Stokes gauge was installed on the intermediate bulkhead to check for leaks and a leak found in one of the PLIS sensing lines was corrected. The test was completed with only one hold at T-45 minutes due to an air conditioning problem. Prior to the third Flight Control and Propellant Tanking Test conducted on November 16, the insulation panels were removed to permit X-raying of the STA 408 area. The X-ray results were satisfactory, the insulation panels replaced and the tanking was conducted with satisfactory results. A special Centaur LO_2 tanking test was conducted on November 27 to verify the fixes to increase the temperatures of the H_2O_2 system. The results of the test were satisfactory.

The Flight Acceptance Composite Test was successfully accomplished on November 24 with only minor discrepancies encountered.

The Composite Readiness Test was completed successfully on November 30. Review of data showed only two minor discrepancies.

The mass model was encapsulated and mated to Centaur on October 19. Following the Flight Acceptance Composite Test the encapsulated mass model was demated on November 25 and remated to Centaur on December 1.

The first attempted launch was December 4. After a delay of 5 hours 13 minutes due to a short in the airborne side of the ATLAS umbilical plug, P1002, the attempted launch was terminated at T-84 due to severe weather warning. The second attempt to launch was December 5. The countdown proceeded normally until at T-5, the launch was terminated due to severe weather warning. The third and successful attempt to launch was December 11 at 0925:02.548 EST.

AC-4 MILESTONES

	Date
Arrival of Atlas Booster 146D	7/23
Arrival of Interstage Adapter	7/28
Erection of Atlas Booster 146D	7/30
Erection of Interstage Adapter	8/4
Arrival of Centaur 4C	8/14
Erection of Centaur 4C	8/20
Arrival of Insulation Panels	9/8
De-erection of Atlas/Centaur (Hurricane Dora)	9/8
Erection of Atlas Booster 146D	9/14
Erection of Interstage Adapter	9/15
Erection of Centaur 4C	9/16
Erection of Insulation Panels	10/1
Arrival of Nose Fairing and Mass Model	10/6
A/P and Guidance Integrated Test	10/16
Encapsulation of Mass Model	10/19
Mating of Mass Model	10/19
A/P and Guidance Integrated Test	10/22
Flight Control and Propellant Tanking Test	10/27
Flight Control and Propellant Tanking Test	11/6
Flight Control and Propellant Tanking Test	11/16
Flight Acceptance Composite Test	11/24
Demate Encapsulated Mass Model	11/25
Centaur Special LO_2 Tanking	11/27
Composite Readiness Test	11/30
Mating of Encapsulated Mass Model	12/1
Attempted Launch	12/4
Attempted Launch	12/5
Launch	12/11

AC-4 COUNTDOWN

F-2 Days

Tank Atlas with fuel

F-1 Day

Atlas/Centaur A/P Readiness Test
Atlas/Centaur TLM/RF System Test
Nose Fairing Bottles Storage
H_2O_2 Tanking and Passivation
Insulation Panel Jettison Reservoir Storage
Engine Trich Auto Flushing
Main Engine Hypergol Purge
Boost Pump and Attitude Engine Firing
Installation of Pyrotechnic Devices

F-0 (Launch) Day

	Start	Complete
Atlas and Centaur Range Safety Command Destruct Boxes Installation	T-360	T-300
Atlas/Centaur A/P Testing	T-335	T-300
Range Safety Command Test	T-230	T-215
Guidance A/P Integrated Test	T-145	T-70
Tower Removal	T-120	T-80
Guidance Final Alignment	T-80	T-45
Centaur LO_2 Tanking (55 percent)	T-70	T-60
Atlas LO_2 Tanking	T-60	T-40
Centaur LH_2 Tanking	T-40	T-1:30
Centaur LO_2 Topping	T-22	T-6
Atlas LO_2 Topping	T-15	T-2:35
Guidance to Flight Mode	T-4	------
Programmers to Arm	T-60 sec	------
Guidance to Internal	T-8 sec	------
Engine Start - Automatic Sequence	T-8 sec	------
2 inch rise	T-0	------

LAUNCH ON TIME CAPABILITY ANALYSIS

The first launch attempt on December 4, 1964 went into the T-90 hold at 7:33 a.m. A normal count from this point would have permitted launch 13 minutes after the opening of the window, however, the weather did not permit this.

The second launch attempt on December 5, 1964 was scrubbed at the hold of T-5 for weather. The count proceeded normally to T-5 at 8:45 a.m. and held at this point, fully tanked, for 29 minutes prior to the initiating of abort procedures at 9:14 a.m. EST. Had weather not dictated an abort, this launch attempt could have met the minimum lunar window.

On the third launch attempt on December 11, 1964, liftoff occurred at 9:25:02.548 a.m. EST. This obviously did not meet a 20-minute lunar window opening at 9:00 a.m. The planned hold of 60 minutes at T-90 was extended to 95 minutes by the launcher stabilization problem. Utilization of the 10-minute absorbing hold at T-5 permitted launch at 9:25; launch would have been at 9:35 without the availability of the 10 minute cushion. However, launch could have been at 9:10, if the absorbing hold of T-5 had been 25 minutes as originally called for in Section 8.4 of the Unified Test Plan. The built in absorbing hold at T-5 was reduced from 25 minutes to 10 minutes at the request of GLO with the anticipation of an Atlas sustainer lube oil temperature problem.

NOSE FAIRING RECOVERY ATTEMPT

As an aid to the recovery of the AC-4 nose fairings, three dye markers were installed in each half of the nose fairing prior to flight, and the Ranger Recovery Ship "Rose Knot" was stationed at the nominal predicted impact point, 554 NM down range on an azimuth of 102.5° true. Impact occurred at the predicted time of T+1026 seconds as reentry and impact was visually observed by several individuals aboard the recovery ship. Impact occurred between 3 and 4 miles away from the ship, and a good azimuth fix was obtained, as visibility was good and the sky clear. The sea ranged from 5 to 7 feet with some whitecaps. The ship proceeded directly to the impact area with hopes for recovery. The ship swept the area until dark, but could find neither the fairing nor any sign of dye in the sea. Two aircraft swept the area for over 3 hours, as long as the fuel supply permitted, and found no evidence of either the fairing or of the dye. There was no reported sighting of the other fairing.

The reentry of the observed fairing was described as rapid and without flutter; and it is the opinion of the recovery observers that the sighted fairing sank upon impact and did not return to the surface.

SECTION 4. MECHANICAL GROUND SUPPORT

SUMMARY

The Mechanical GSE worked satisfactorily for the AC-4 Flight. The only problem was a slow LH_2 tanking rate on the December 5th launch attempt and a leaking regulator valve on launch day. These are discussed below. The environmental control system was within parameters. Gas and propellant supplies were adequate for a sustained hold had they been needed. The LOX and LH_2 propellant loading systems had no problems and Atlas LOX red-line temperatures were met without dumping LOX as was necessary on AC-2 and AC-3.

PROBLEMS

a) LH_2 Loading Rate

After the slow tanking rate of approximately 5 percent/minute on the December 5 launch attempt the following LH_2 samples were taken from the storage tank.

1. 12/8/64 - Liquid agitated by pressurizing and venting then dumping approximately 500 gallons before sampling. Results, 100 ppm N_2 and 5 ppm O_2.

2. 12/9/64 - A.M. Tank topped off and sample taken several hours later, results, 190 ppm N_2 and 0.8 ppm O_2.

3. 12/9/64 - P.M. Results, 29 ppm N_2 and 0.7 ppm O_2.

In addition, the LH_2 transfer line was purged and sampled for GN_2 and O_2. The normal transfer line He purge consists of a 1-hour purge on F-2 days with no sample taken or further purge till LH_2 loading. On F-2 day for AC-4 the line was purged with He from the F/D valve to the storage tank outlet valve for 1 hour and sampled. The results showed 1.4 percent GN_2 and 0.38 percent O_2.

The purge was continued for an additional hour and sampled. The results were 0.045 CN_2 and 0.004 O_2. This indicates a lack of adequate purging of the transfer line in the past.

On launch day the line was purged for 1 hour and sampled prior to start of LH_2 loading. The tanking rate started at 11 percent per minute and leveled out at 8 percent per minute with the flow control valve wide open. This is considered normal flow rate.

b) Launcher Booster Unit Regulator

During the hold at T-90 a GN_2 regulator that supplies 2000 psig pressure to the Launcher Auxiliary A frame stabilizing system leaked, causing the pressure to go above 2000 psig. The correct configuration regulator in this panel had been replaced with one which had a larger orifice for more rapid charging of the system, but this regulator leaked. The correct regulator was installed and worked satisfactorily.

ENVIRONMENTAL CONTROL SYSTEM

These temperatures and pressures are taken in the A/C ducts

(a) Upper Stage Cooling - [(55° F + 5° - 10°).(0.433 psig minimum)]

F-1 day - The temperature varied from 44° to 46° F.

The duct pressure varied from 0.85 to 0.90 psig.

Launch day - The temperature remained steady at 44° - 46° F.

The pressure varied from 0.75 to 0.80 psig.

T-90 min (GN_2 flow) - Temperature climbed from 46° to 50° F and held steady to lift-off.

Pressure was steady at 0.82 psig.

NOTE: These GN_2 temperatures were achieved by by-passing the dehumidifier cooling coils.

(b) Centaur Thrust Section [(130° F±10°)(0.47 psig minimum)]

Launch Day - 119° F gradually increasing to 122° F then 125° F and steady to lift-off.

Pressure started at 0.85 psig and jumped to 0.975 at 5:30 a.m., decreased to 0.94 at lift-off.

(c) Atlas Pod Cooling [(50° F max.)(0.83 psig to 1.44 psig)]

Launch Day - Temperature steady at 43.4° F down to 39.4° F just prior to launch. Pressure steady at 1.02 psig.

(d) Atlas Thrust Section Heater (147° F minimum with LOX)

Launch Day - At 6:30 a.m. the temperature jumped from 60° F to 176° and held steady to lift off.

(e) P/L adapter ring O/S 171

Launch Day - This temperature on the payload adapter was between 50° - 60° F during the T-90 hold. It climbed gradually to 75° at T-40. (LH_2 chilldown complete). Then down to 0° at T-25 and -25° at T-10. This held steady to lift-off.

GAS AND PROPELLANTS

(a) A/C GN_2 Supply

Total water volume including 28 tube bank trailers	-	11,607 cu ft
Total SCF available	-	1,360,000
Total SCF Used	-	244,000
Total SCF available at lift-off	-	1,116,000
Hold time available at lift-off	-	200 minutes

This is in addition to the 70 minutes required after start of detanking. Total time on GN_2 flow was 90 minutes.

(b) He Insulation Panel and Engine Purge

Total water volume from 12 tube bank trailers - 4,164 cu ft

Total pounds available at 6:45 a.m.	2400
Total pounds available at T-0	1848
Hold time available at T-0	234 minutes

This does not include the 4 hours required for warm-up after detanking.

(c) He for LOX Transfer

Total water volume available from three tube bank trailers - 1041 cu ft

SCF available at 6:45 a.m.	123,381
SCF used	38,940

(d) Atlas Thrust Section Heater GN_2

Total water volume available from 1 tube bank trailer - 273.9 cu ft

SCF available	34,200
SCF used	6,300

GN_2 flow was on for 6 minutes

(e) Launcher Booster Unit GN_2

Starting pressure	6700 psig
Ending pressure	5700 psig
Minimum pressure required	5400 psig

(f) Facility Gases

1. Facility GH_2 (3000 psig)

Starting pressure	2300 psig
Ending pressure	1860 psig
Minimum pressure	1100 psig

2. Facility He (3000 psig)

Starting pressure	2800 psig
Ending pressure	2610 psig
Minimum pressure	1500 psig

3. Facility He (6000 psig)

Starting pressure	5600 psig
Ending pressure	4500 psig
Minimum pressure	3550 psig

(g) LOX

Storage Tank level at start	30,650 gal.
Storage Tank level at end	7,350 gal.
LOX used	23,300 gal.

NOTE: The level gage transducers on both storage tanks were rejected after inspection, therefore, the above figures are an approximation.

(h) LH_2

Storage tank level at start	- 1005 gal.
Storage tank level at end	- 755 gal.
LHe used	250 gal.

Approximate hold time remaining 42 minutes

SECTION 5. TRAJECTORY

SUMMARY

The Atlas-Centaur vehicle AC-4 was launched from ETR Complex 36A on December 11, 1964 at 0925:02.548 EST. Preliminary evaluation of quick-look tracking and orbit data indicate that the actual trajectory was nearly that desired. The deviations from the desired trajectory that occurred during booster phase were properly compensated for by the guidance system and, as a result, AC-4 was injected into a near nominal circular orbit.

ATMOSPHERIC AND AERODYNAMIC PARAMETERS

The atmospheric conditions estimated to exist at the time of launch are presented in Figure 5-1. These data were determined from a Rawinsonde run made at 0905 EST, approximately 20 minutes prior to liftoff. The temperature and pressure profiles are presented in Figure 5-1a as functions of altitude. A comparison of the measured and the predicted wind profile which was assumed for the preflight simulation is presented in Figure 5-1b. The East-West component shifted such as to decrease the tail-wind assumed in the preflight. The cross wind (North-South) was also stronger than predicted. These shifts in the winds resulted in the measured angles of attack which are presented in Figure 5-2. The significance of the changes in the angles of attack will be discussed in the section on structures, Section 10.

A major weather problem was the surface winds which were gusting to velocities of 19 knots, a velocity above the limits for some of the loading configurations. However, the weather-structural analysis program indicated that there was a sufficient margin of safety for the AC-4 configuration.

The dynamic pressure and Mach number histories are presented in Figure 5-3. The peak dynamic pressure occurred at T+80 seconds and was approximately 60 psf greater than predicted. The Mach number was slightly higher than obtained in the preflight simulation. This would indicate that the peak aerodynamic drag was also somewhat greater than anticipated.

TRAJECTORY COMPARISONS

A comparison of the actual and the predicted trajectories is presented in Figures 5-4, 5-5, and 5-6 in terms of position, axial load factor (thrust acceleration), and relative velocity (relative to the air), respectively. The trajectory called "actual" on the figures is based on the tracking data used by GSFC to pre-position the downrange radars for acquisition of the vehicle when it came into range. It is essentially the trajectory computed by the Instantaneous Impact Prediction program.

The altitude was approximately 3σ high at BECO, Figure 5-4, which occurred about 1.5 seconds early, Table 2-1. Also, the axial load factor and relative velocity were higher than planned, Figures 5-5 and 5-6. This would indicate that the booster performance was slightly better than predicted. Similar results were obtained for the AC-2 and AC-3 flights. Following BECO, at which time the guidance system was activated, the dispersions in altitude were gradually reduced until at MECO the desired orbit injection conditions were obtained. Other possible causes contributing to the lofted trajectory could be a lower than planned pitch rate during the time prior to BECO and the shift in the wind profiles. A small discrepancy in crossrange (slighly to the right of the desired trajectory) was observed,

Figure 5-4c. The possible causes of the crossrange deviation could be the strength of the North-South wind components and the degree of accuracy with which the Atlas autopilot established the pitch-over azimuth.

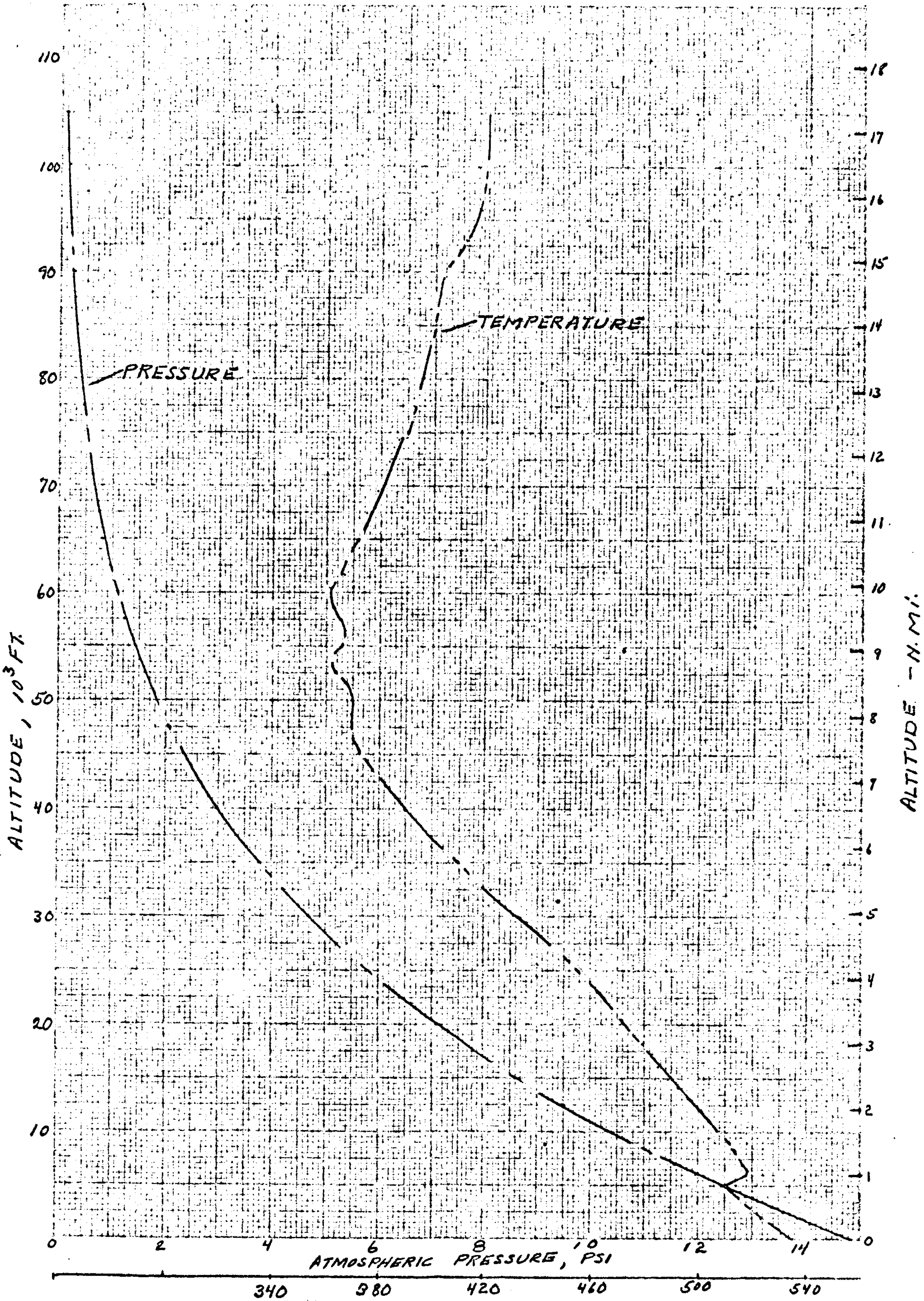
AC-4 was injected into a nearly circular 90 n. mi. orbit 572.76 seconds following liftoff. The actual orbit determination made by GSFC is compared with the desired orbit in Table 5-1. The deviations are very small with the injection and perigee altitudes being within 0.2 n. mi. of the desired values. The apogee altitude was within 5 n. mi. (higher), but still within the 3σ value.

TABLE 5-1

ORBITAL PARAMETERS

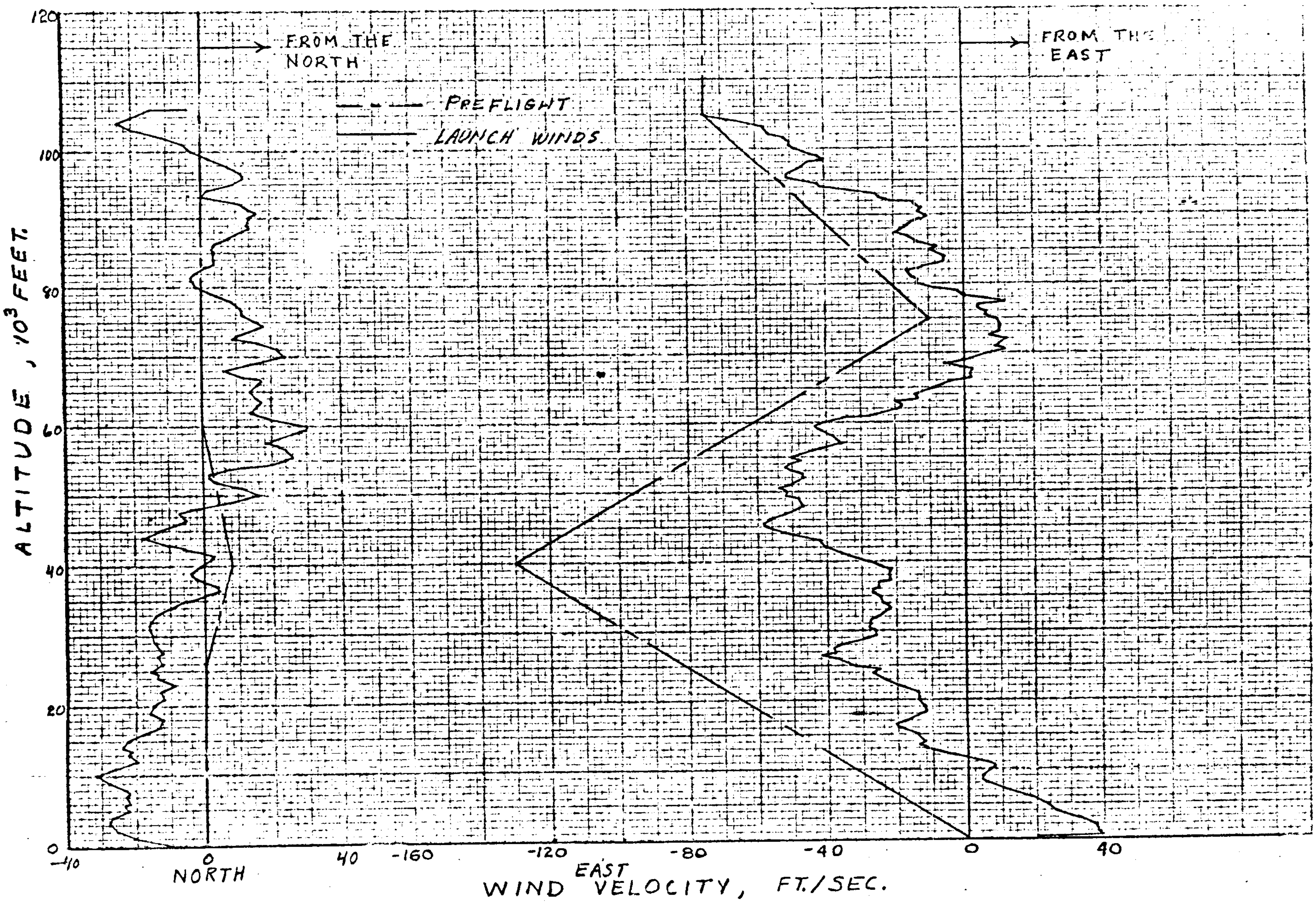
	Units	Predicted (3)	Actual (4)	Actual less predicted	3σ
Time of epoch[1]	Sec	573.7	572.7	-1.0	8.6
Period	Min	87.78	87.86	+0.08	.005
Inclination	Deg	30.73	30.69	-.04	.04
Eccentricity	---	.0001	.00095	+.00085	.002
Perigee altitude[2]	N.Mi.	88.41	88.20	-.21	7.5
Apogee altitude[2]	N.Mi.	89.24	94.92	+5.68	7.4

[1]Time measured from 2-inch motion, that is, from 0925:02.548 EST.
[2]Measured above spherical Earth, R_o = 3444 N.Mi.
[3]Data obtained from GD/A Report No. GD/A-BTD 64-072, September 15, 1964.
[4]Determined by GSFC.



a. PRESSURE AND TEMPERATURE.

FIGURE 5-1. ATMOSPHERIC CONDITIONS AT TIME OF LAUNCH



b. WIND COMPONENTS.

FIGURE 5-1 ATMOSPHERIC CONDITIONS AT TIME OF LAUNCH

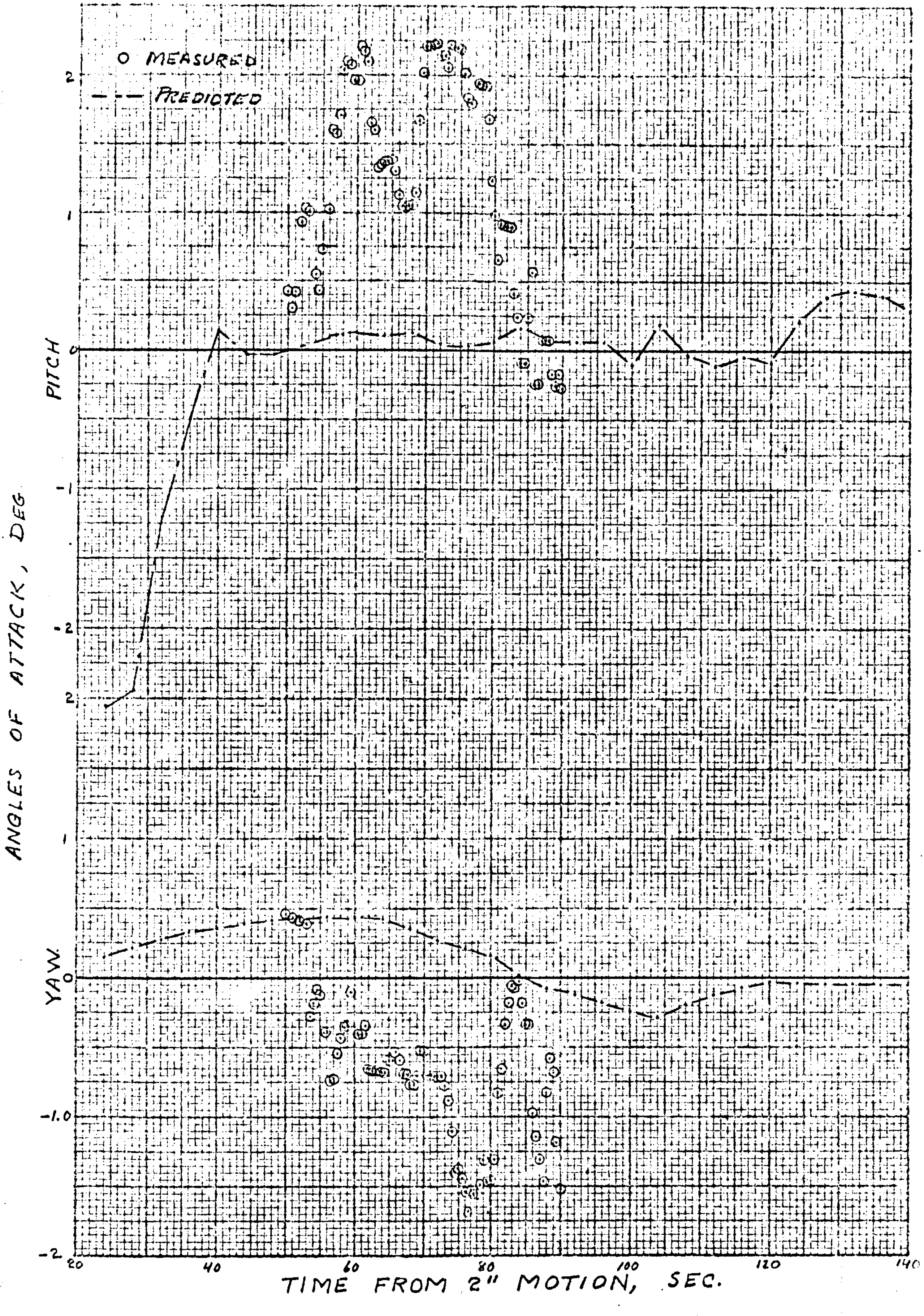


FIGURE 5-2 ANGLES OF ATTACK.

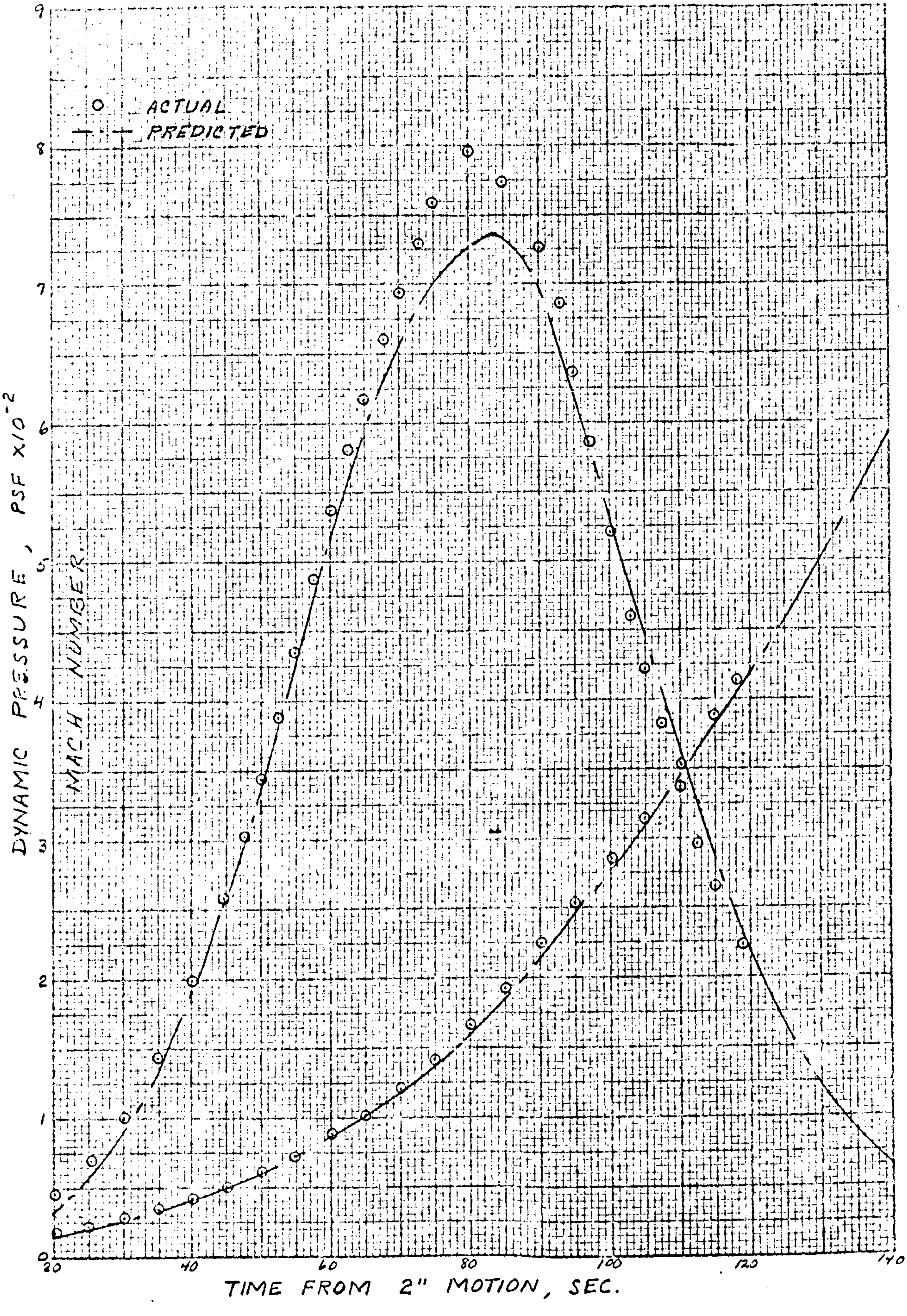
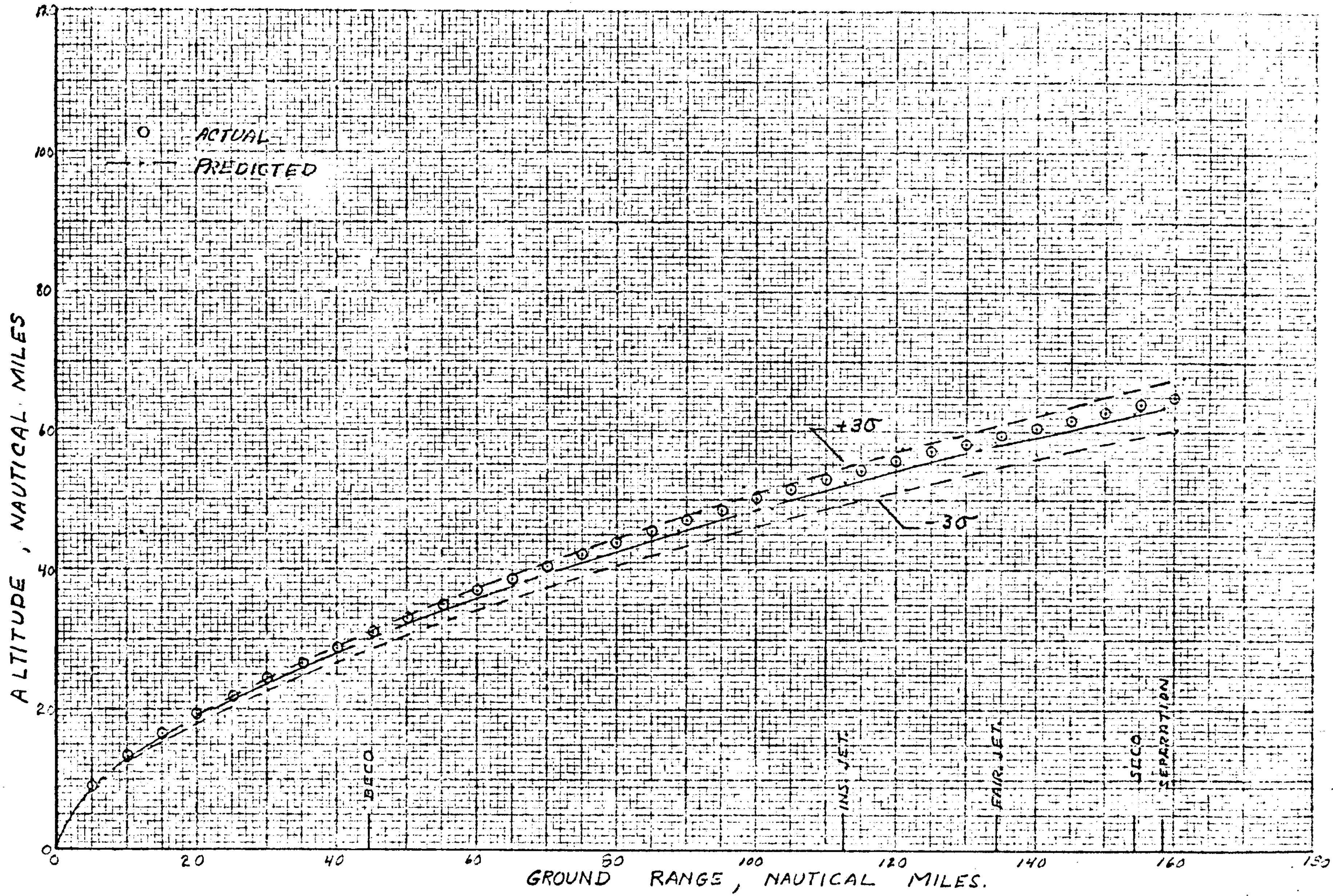
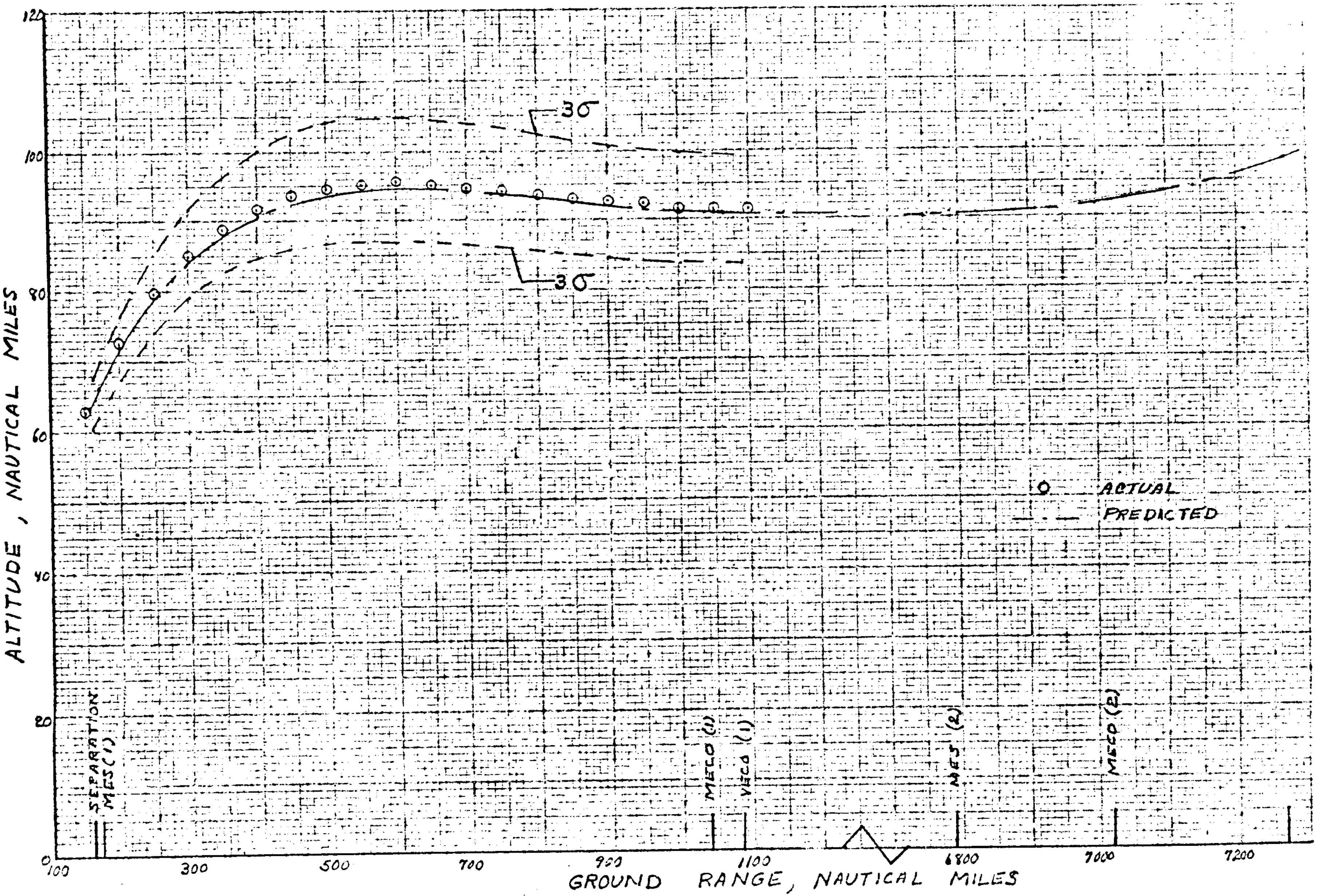


FIGURE 5-3. AERODYNAMIC PAPAMETERS



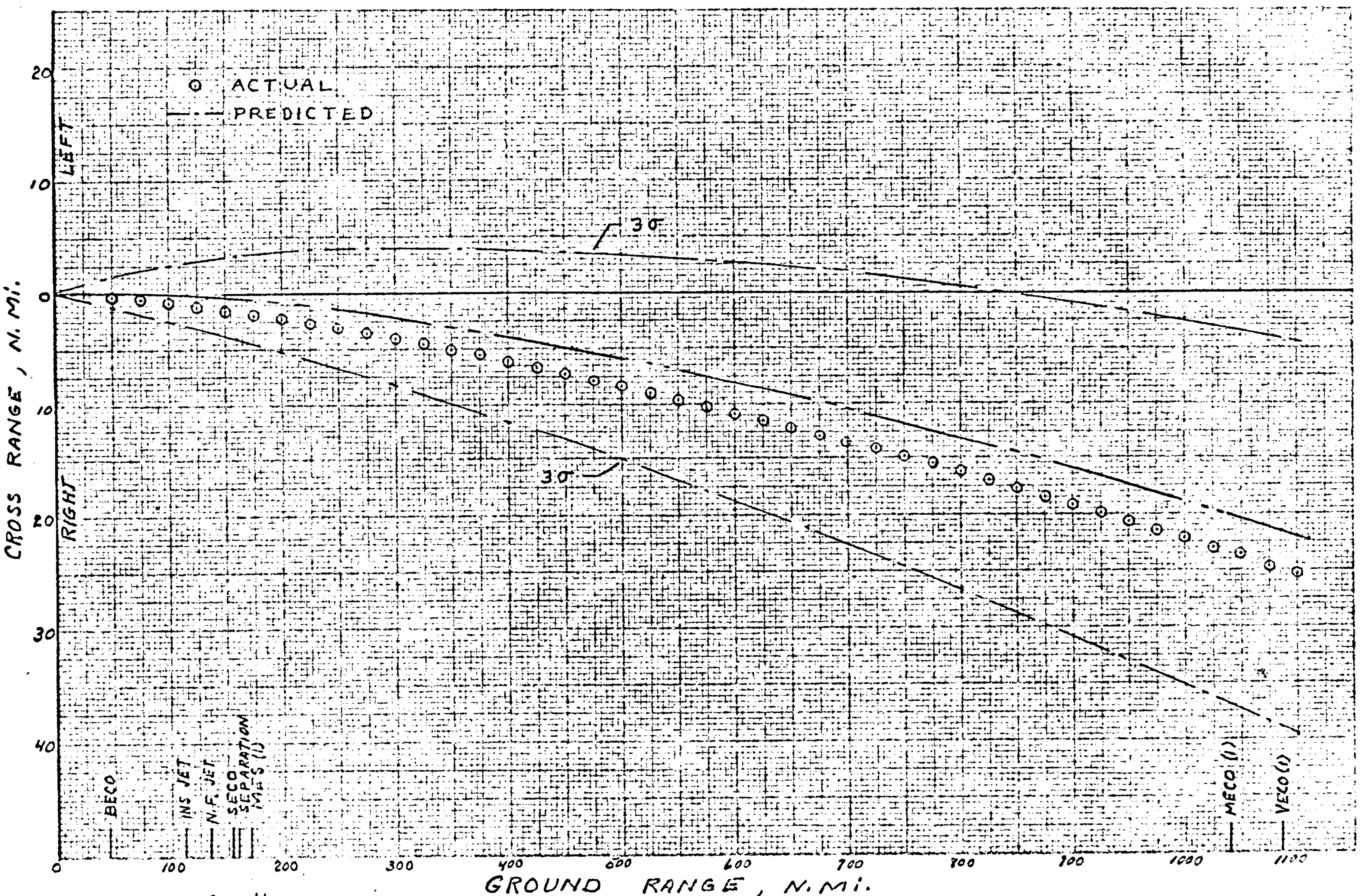
a. VERTICAL TRAJECTORY - ATLAS PHASE

FIGURE 5 - 4 POSITION COMPARISON



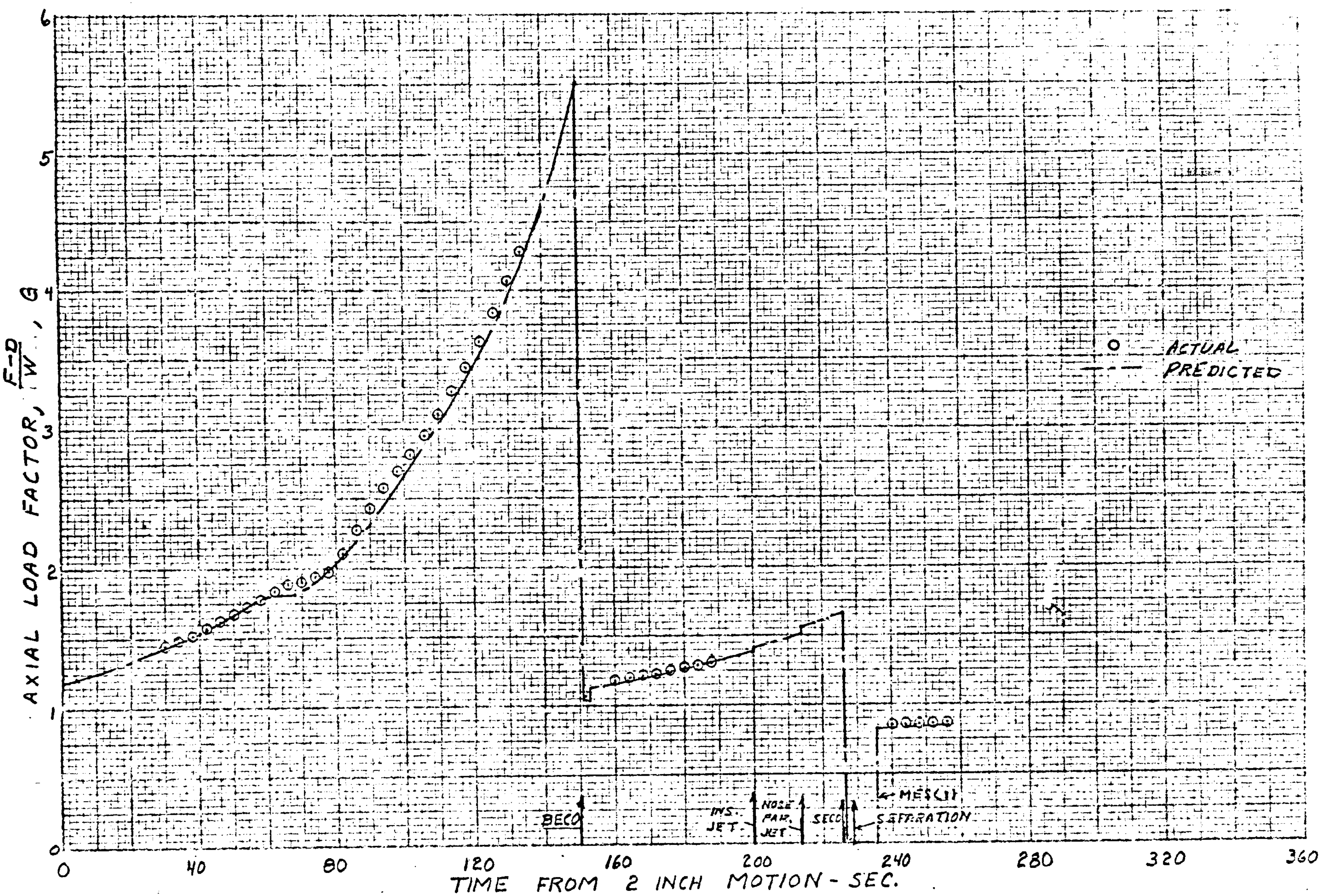
b. VERTICAL TRAJECTORY - CENTAUR PHASE

FIGURE 5-4 POSITION COMPARISON



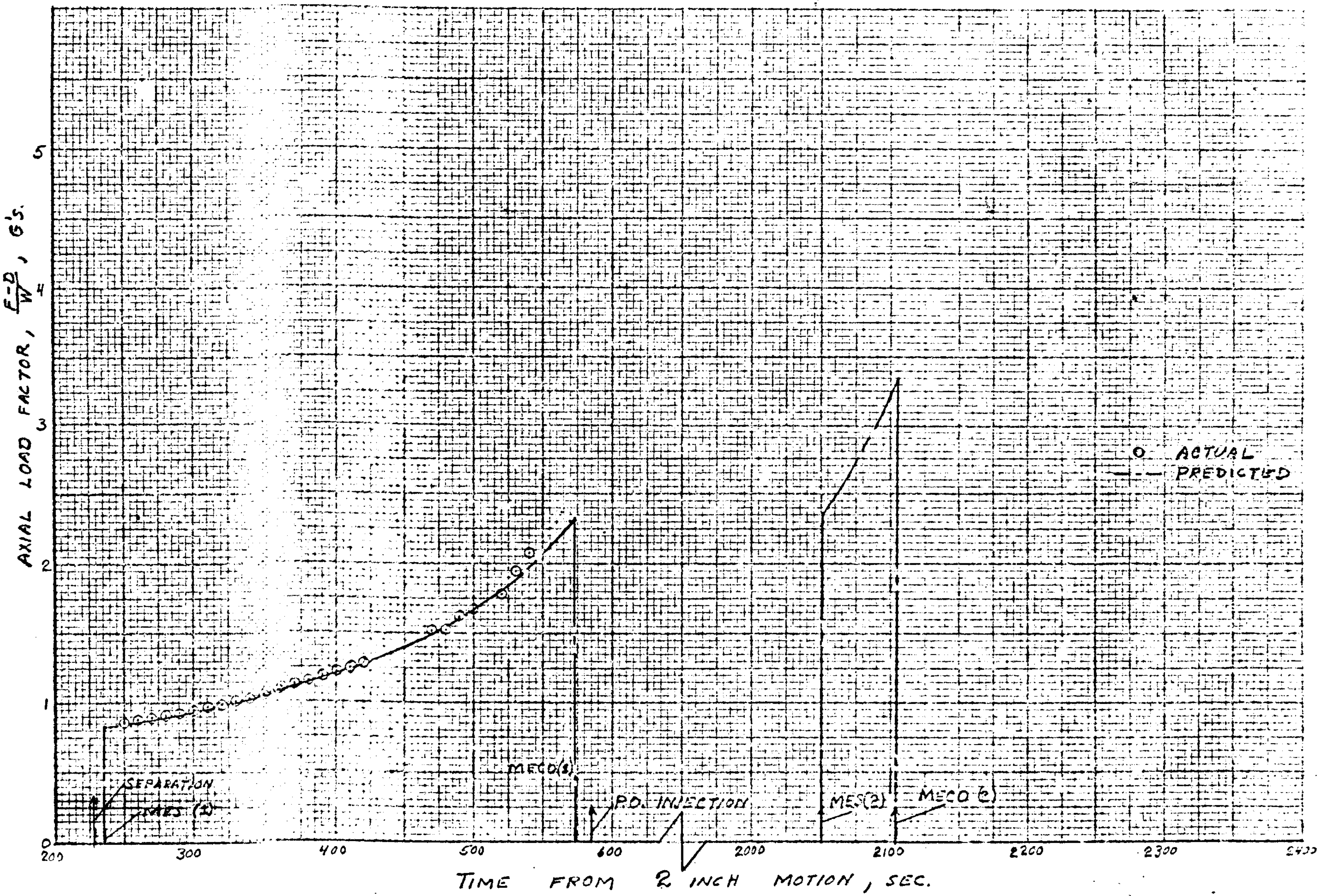
C. HORIZONTAL

FIGURE 5-4 POSITION COMPARISON



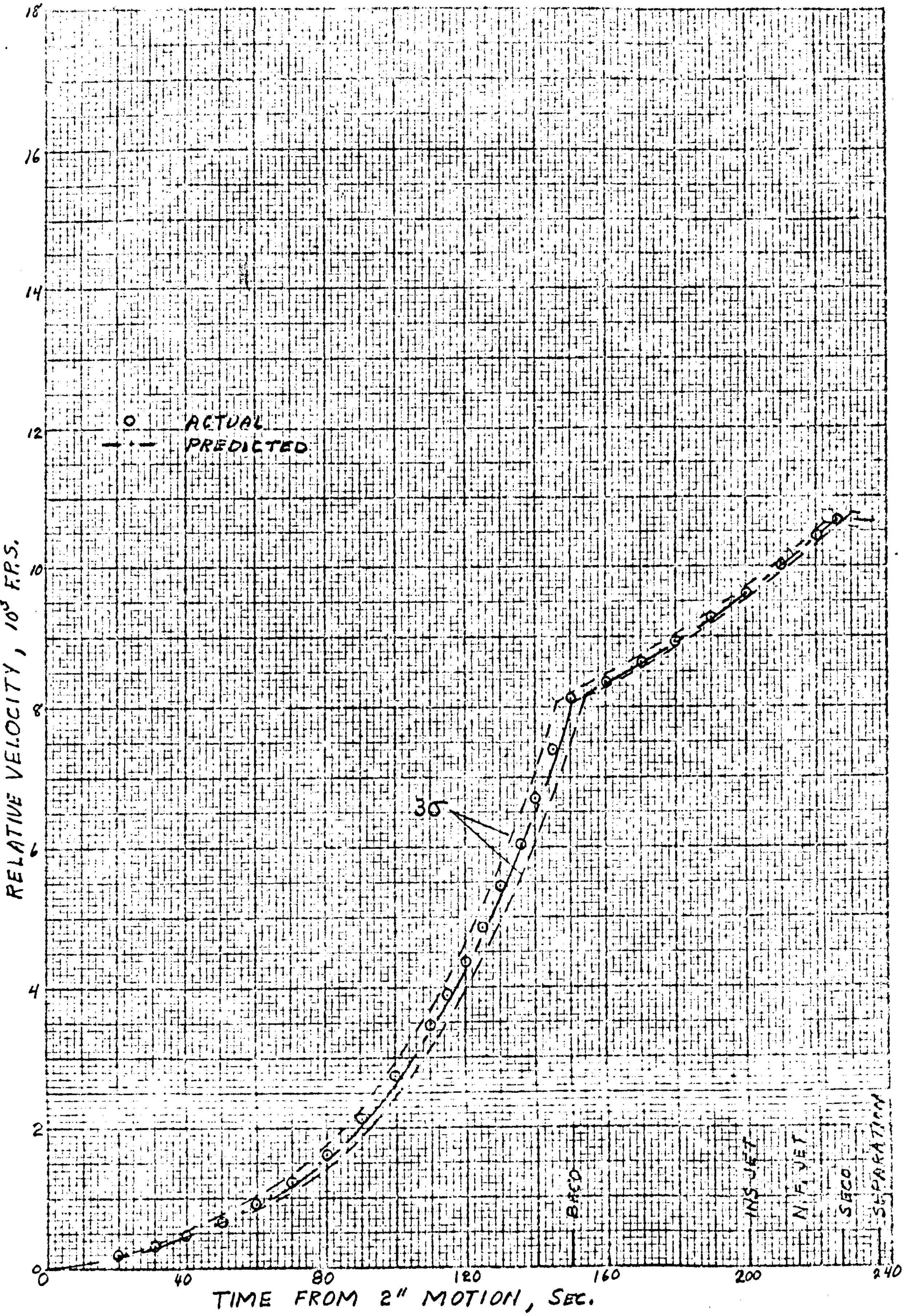
a. ATLAS PHASE

FIGURE 5 - 5. THRUST ACCELERATION COMPARISON



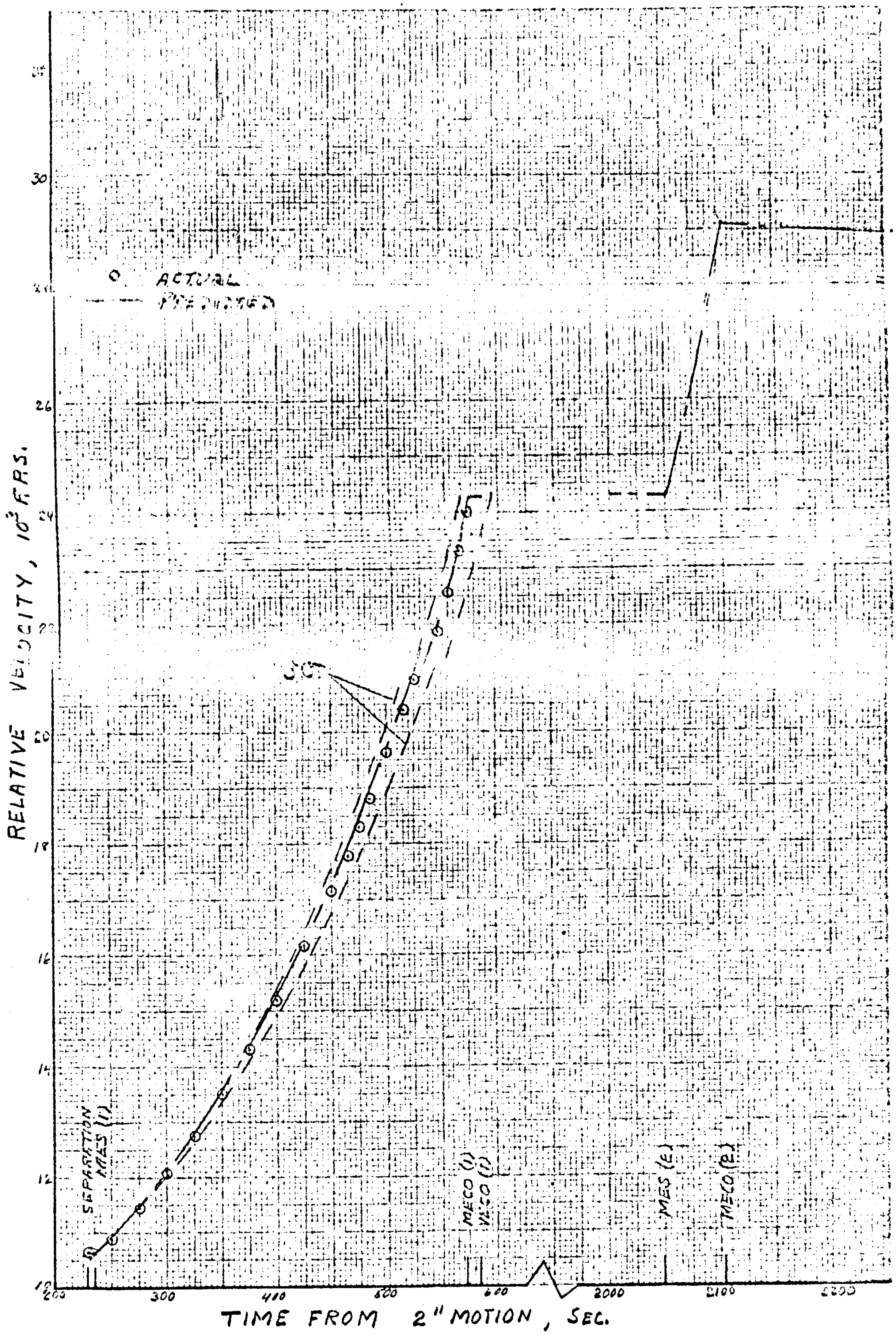
b. CENTAUR PHASE

FIGURE 5-5. THRUST ACCELERATION COMPARISON



a. ATLAS PHASE

FIGURE 5-6 RELATIVE VELOCITY COMPARISON



b. CENTAUR PHASE

FIGURE 5-6. RELATIVE VELOCITY COMPARISON

SECTION 6. PROPULSION INTRODUCTION

SUMMARY

Atlas performance was almost as predicted throughout the entire flight. Centaur propulsion exhibited no major problems during the first burn. The second burn of the Centaur engines was not achieved.

A propulsion system sequence of events is given in Table 6-1.

ATLAS PROPULSION

Table 6-2 lists the Atlas thrust, specific impulse, and mixture ratio at liftoff, BECO, and SECO and compares them with their predicted values. The PU valve setting was 1.8 degrees below the "nominal" 26.7 degree setting at liftoff and was 5.1 degrees low at both BECO and SECO. This is due to Vehicle 146D being orificed to a 2.28 to 1 mixture ratio whereas the previous vehicles were orificed to a ratio of 2.359 to 1.

CENTAUR OVERALL PERFORMANCE

Centaur performance in terms of thrust, specific impulse, and mixture ratio are listed in Table 6-3. These values are subject to change with additional data aquisition.

The start total impulse for the C-1 engine is 3420 lb-sec and for the C-2 engine is 3360 lb-sec.

MAIN ENGINE

Table 6-4 compares some nominal engine operating parameters with those measured during flight. Figure 6-1 and 6-2 illustrate the fuel and LOX pump NPSH both during the start transient and for steady state. Figure 6-3 exhibits fuel pump housing temperature versus time. No major anomaly has been discovered in the engine system operation. Figure 6-4 shows the rise of chamber pressure with time during the start transient.

BOOST PUMPS

This was the first Centaur flight in which a reduced power fuel boost pump was used. The fuel unit flown (serial number 80) was orificed to operate during steady state at a 45,955 rpm turbine speed with a corresponding head rise of 15.15 psid. The LOX boost pump (serial number 67) was orificed to provide 27.3 psid head rise at 32,580 rpm steady state. Boost pump start signal was initiated 16.2 seconds prior to SECO. The start sequence was very close to the planned times as exhibited below.

	Planned	Actual
BPS to prestart	20.6 sec	19.83 sec
P/S to main engine start	6.0	5.93
BPS to main engine start	26.6	25.76

Except for CP28P (fuel boost pump turbine nozzle box pressure) times from start signal to first indication of gas generator and nozzlebox pressures were approximately 1 second for both the LOX and fuel boost pumps. CP28P failed to rise until 9 seconds after the start signal. This is attributed to a failure of the transducer since the upstream gas generator pressure, as well as turbine speed and head rise rose immediately.

The plots of turbine speed and head rise in Figures 6-5 and 6-6 show a variation from the expected values for the start transient, particularly for the fuel boost pump. These plots were made from data received from Tel-2 and the absolute magnitudes are questionable.

This data shows that the fuel boost pump speed during the first 35 seconds of boost pump operation was approximately 8000 rpm higher than anticipated. Similarly, the fuel boost pump head rise is approximately 4 psid higher than expected. LOX boost pump performance as shown in these figures was very close to the expected values.

Down-Range Data

(See the following table) indicates that the fuel boost pump speed is approximately 2000 rpm higher than expected, although head rise is within 1 psid of the nominal values. Fuel gas generator pressure was normal, with nozzlebox pressure from 4 to 8 psi higher than expected. Turbine speed, nozzlebox pressure, and head rise are within the band of telemetry accuracy. The LOX boost pump down-range data shows that turbine speed and head rise are normal at MECO. However, the gas generator and nozzlebox pressures are questionable, particularly since the nozzlebox pressure is higher than gas generator pressure which is an impossibility. Further investigation is in progress to determine the cause of this inconsistancy.

DOWN-RANGE DATA

	P/S	MES	MES + 60	MECO	Initial acceptance test, steady state
Fuel B. P. Speed, rpm	51,070	49,400	48,070	48,115	45,955
Fuel B. P. nozzle pressure, psia	140	140	--------	142	136.5
Fuel B. P. G. G. pressure, psia	149.8	149.8	--------	152.1	153.5
Fuel B. P. head rise, psid	27.0	25.2	16.0	14.9	15.15
LOX B. P. speed, rpm	36,500	37,390	--------	32,860	32,580
LOX B. P. nozzle pressure, psia	82.5	87.5	--------	112.5*	95
LOX B. P. G. G. pressure, psia	98	98	--------	101*	107
LOX B. P. head rise, psid	71.75	71.75	--------	26.2	27.3

*Values questionable.

The following temperature measurements were evaluated and appear to be normal out to T + 1080 seconds from liftoff except where noted.

SELECTED TEMPERATURE MEASUREMENTS (TEMPERATURES IN $^{\circ}F$)

	Liftoff	BPS	MECO	+1080
CP80T Helium chill line temperature	-408	OSH	OSH	OSH
CP27T LOX B. P. turbine nozzle temperature	OSL	175	1100	750
CP127T Fuel B. P. turbine bearing	105*	100*	270	315
CP36T LOX B. P. turbine bearing	70	65	190	240
CP29T Fuel B. P. turbine nozzle temperature	150*	150*	1105	Lost at +610 seconds
CP18T LOX B. P. H_2O_2 cont. vlv. in.	65	63	86	83
CP20T LH_2 B. P. H_2O_2 cont. vlv. in.	60	40	75	78
CP336T LH_2 B. P. varobox	58	42	--	145
CP337T LH_2 B. P. H_2O_2 cont. vlv	64	70	--	145
CP 32T LH_2 B. P. inlet temperature	-421	--	-422.2	-421.2
CP33T LOX B. P. inlet temperature	-281.5	-281.3	-284.7	-284.8
CP885T LOX B. P. discharge temperature	------	-282	-284.4	-284
CP884T LH_2 B. P. discharge temperature	-421	-421.3	-422	OSH at +700 seconds

*Values questionable.

It appears that CP29T transducer failed at liftoff plus 610 seconds as evidenced by the sudden drop in temperature from 1105° F to zero. This transducer senses the mass temperature and ordinarily takes considerably longer to cool.

CP884T (LH_2 boost pump discharge temperature) which went off scale high at liftoff plus 700 seconds apparently is due to loss of liquid in the discharge after MECO. This, in turn, is possibly due to boiloff in the ducts or liquid moving forward in the tank.

Further investigation is necessary to draw a conclusion.

ATTITUDE CONTROL SYSTEM

The attitude control system temperatures appeared to be normal. The H_2O_2 bottle remained steady at approximately 80° F. Figure 6-7 shows abrupt temperature changes in the two fuel supply lines at about 1421:50z. This was caused by pressurizing the H_2O_2 system at this time. Normally, change at this time would be an increase in temperature caused by the warmer H_2O_2 from the bottle entering the lines. A possible explanation for the drop in the P-2 fuel supply line temperature is that the line was not completely purged prior to pressurization, and when the system was pressurized colder H_2O_2 in the upstream line moved to the location of the transducer. The increase in fuel supply line temperatures to near bottle temperature after MECO is normal and indicates H_2O_2 flow in the lines.

Figure 6-8 shows the attitude engine cluster manifold temperature. The drop at T-0 is caused by the termination of ground air conditioning at launch. At 1426:20z the temperatures began to increase. This is attributed to aerodynamic heating. Later flight data is not available at this time. The ullage control engine combustion chamber temperatures are shown in Figure 6-8. The Q-1 unit temperature at launch (260° F) is much higher than it should be. Since the temperature went off scale after firing the engines at MECO, the high initial temperature is attributed to instrumentation error. The Q-2 unit temperature prior to MECO is considered to be too low (-6° F). The reason for this is still under investigation. The increase in temperature of both units at MECO does indicate normal ullage control engine firing.

Ten-tone data which indicates attitude control engine firing times is not presently available for the period between SECO and MES. The data from the first 8 minutes of the coast phase shows that the P-2 engine fired for a fifteen second period shortly after MECO. This was probably to correct a pitch error due to MECO transients. P-1, A-1, and A-2 engines fired infrequently during this early portion of the coast period. A-3 and A-4 engines fired with a duty cycle of about 0.9 second on, and 1.7 seconds off almost constantly from MECO to MECO + 267 seconds. There are several things that could possibly have caused this yaw error. With the propellants in the forward end of the tank after MECO, the center of gravity of the vehicle was moved forward and the ullage control engines could create a couple about the center of gravity. A second possible cause would be exhaust gas impingement from the ullage control engines on the LOX sump. Another cause could be a leak in any pressure line on the vehicle. Further study of the data is required in this area. At MECO + 267 seconds, when the LH_2 vent valve opened, A-3 and A-4 engines remained on almost constantly until the end of the available data at MECO + 8 minutes. It is evident that the venting of LH_2 caused a torque on the vehicle above the recovery capability of the attitude control engines.

HYDRAULIC SYSTEM PERFORMANCE

Preliminary evaluation of the data received from the AC-4 flight shows that both C-1 and C-2 hydraulic systems operated properly. Full system pressure was achieved in 1.5 seconds on both systems and held steady throughout main engine burn. (Figs. 6-10 and 6-11).

At SECO + 0.1 second the circulation systems of C-1 and C-2 engine hydraulics came up to their proper values (Figs. 6-10 and 6-11). The C-1 and C-2 pressures were 111 and 110 psia, respectively.

Both engines moved to null under circulation system power at a rate of approximately 0.3° per second. From SECO + 0.1 to MES + 0 second the pressure profiles and the pitch and yaw feedbacks were quite similar to those of AC-2 and AC-3. Thrust build up and the associated rate transients were such that at MES + 4 seconds the vehicle attitude was very close to that required by guidance when it was readmitted. Consequently, engine gimbal requirement and hydraulic demand was very low. The usual dip in pressure at MES + 4 was nonexistant. Main system pressures were very steady at 1167 and 1188 psia, respectively.

Temperature sensing instrumentation installed to evaluate the redesign of the engine-hydraulic system interface substantiated the results of earlier preflight Sycamore firings. Further information on thermal isolation of the two systems for coast phase evaluation has not been made, however, precoast temperatures were adequate (Figs. 6-13 and 6-14).

TABLE 6-1

SEQUENCE OF EVENTS

	Pre-dicted	Actual	GMT	
Liftoff	0	0	1425	02.55
Booster engine cutoff (BECO)	150.0	149.1	1427	31.6
Centaur boost pump start (BPS)	209.1	208.6	1428	30.6
Sustainer engine cutoff	226.1	224.3	1428	46.9
Centaur prestart (PS)	229.7	227.9	1428	50.5
Centaur main engine start (MES)	235.7	233.8	1428	56.4
Centaur main engine cutoff (MECO)	573.0	572.7	1434	35.2

TABLE 6-2

ATLAS PERFORMANCE

	Actual	Predicted
Thrust at liftoff, lb		
Boosters	307,300	306,940
Sustainer	56,600	56,650
Verniers, axial	1,400	1,710
Total	365,300	365,300
Thrust at BECO		
Boosters	357,900	356,600
Sustainer	79,940	79,760
Verniers, axial	1,600	1,970
Total	439,440	438,320
Thrust at SECO		
Sustainer	79,100	79,100
Verniers, axial	1,460	1,460
Total	80,560	80,560
I_{sp} at liftoff, sec		
Boosters	250.4	250.4
Sustainer	205.8	207.2
Total	243.2	243.6
I_{sp} at BECO		
Boosters	280.5	288.1
Sustainer	297.0	297.8
Total	284.4	291.4
I_{sp} at SECO		
Total	302.4	303.2
LOX to fuel ratio		
Liftoff	2.325	2.240
BECO	2.513	2.336
SECO	2.451	2.228

TABLE 6-3

CENTAUR PERFORMANCE*

(a) C-1 engine (1848)

	Acceptance run	Time from MES, sec					
	P_c = 293.5	5	50	100	150	200	250
Thrust, lb	14,990						
Lewis Venturi		14,838	14,992	14,981	14,992	15,002	14,992
PWA regression		14,942	14,937	14,951	14,937	14,937	14,933
PWA C		15,079	15,217	15,222	15,223	15,227	15,228
Specific impulse, sec	432.0						
Lewis Venturi		428.5	426.1	430.1	427.7	425.7	428.7
PWA regression		431.7	431.8	431.6	431.8	431.9	431.9
PWA C*		430.8	429.9	429.8	429.7	429.6	429.6
Mixture ratio	4.97						
Lewis Ventrui		4.977	5.19	5.067	5.112	5.158	5.112
PWA regression		5.036	5.023	5.054	5.022	5.012	5.012
PWA C*		5.096	5.205	5.227	5.234	5.251	5.254

(b) C-2 engine (1857)

	Acceptance run	Time from MES, sec					
	P_c = 299.3	5	50	100	150	200	250
Thrust	15,018						
Lewis Venturi		14,808	15,017	15,022	15,026	15,037	15,030
PWA regression		14,995	15,000	15,008	14,995	14,991	14,991
PWA C*		14,940	15,148	15,170	15,117	15,191	15,173
Specific impulse	431.0						
Lewis Venturi		428.5	416.6	419.5	419.6	417.2	417.5
PWA regression		431.3	431.2	431.1	431.4	431.4	431.4
PWA C*		433.9	432.8	432.4	432.2	432.1	432.3
Mixture ratio	5.0						
Lewis Venturi		4.98	5.19	5.208	5.226	5.274	5.244
PWA regression		4.963	4.974	4.988	4.957	4.948	4.948
PWA C*		4.627	4.810	4.873	4.90	4.913	4.913

*Much of the Tel 2 data exhibited a drift with time. New data may change some values.

TABLE 6-4

CENTAUR ENGINE STEADY OPERATING CONDITION

Reading	Nominal	MES + 200 sec
C-1 LH_2 pump total inlet pressure, psia	38.4	34.86
C-1 LH_2 pump inlet temperature, ^oR	38.8	38.80
C-1 LOX pump total inlet prsssure, psia	59.8	58.35
C-1 LOX pump inlet temperature, ^oR	176.6	177.69
C-1 LOX pump speed, rpm	11,350	11,300
C-1 LOX pump discharge pressure, psia	464	455
C-1 LH_2 pump discharge pressure, psia	922	921
C-1 Fuel turbine inlet temperature, ^oR	331	342.82
C-1 Fuel Venturi upstream pressure, psia	649	657.5
C-1 Chamber pressure, psia	293.5	294.4
C-2 LH_2 pump total inlet pressure, psia	38.4	37.87
C-2 LH_2 pump inlet temperature, ^oR	38.8	38.66
C-2 LOX pump total inlet pressure, psia	59.8	55.75
C-2 LOX pump inlet temperature, ^oR	176.6	176.17
C-2 LOX pump speed, rpm	11,350	11,400
C-2 LOX pump discharge pressure, psia	464	477
C-2 LH_2 pump discharge pressure, psia	922	969
C-2 Fuel turbine inlet temperature, ^oR	331	342.60
C-2 Fuel Venturi upstream pressure, psia	649	667.1
C-2 Chamber pressure, psia	299.3	298.0

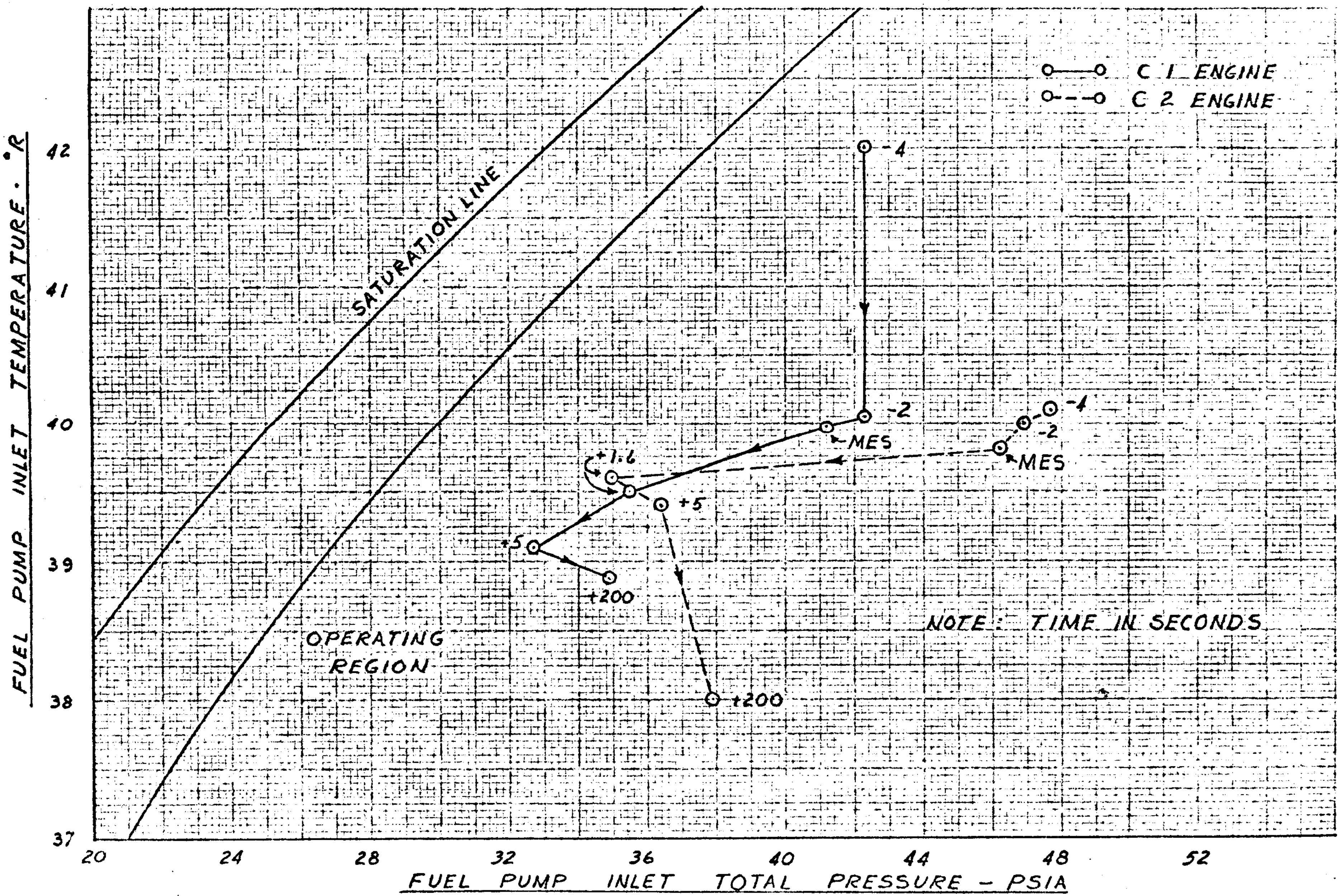


FIGURE 6-1 FUEL PUMP INLET CONDITIONS NEAR ENGINE START FOR THE AC 4 FLIGHT

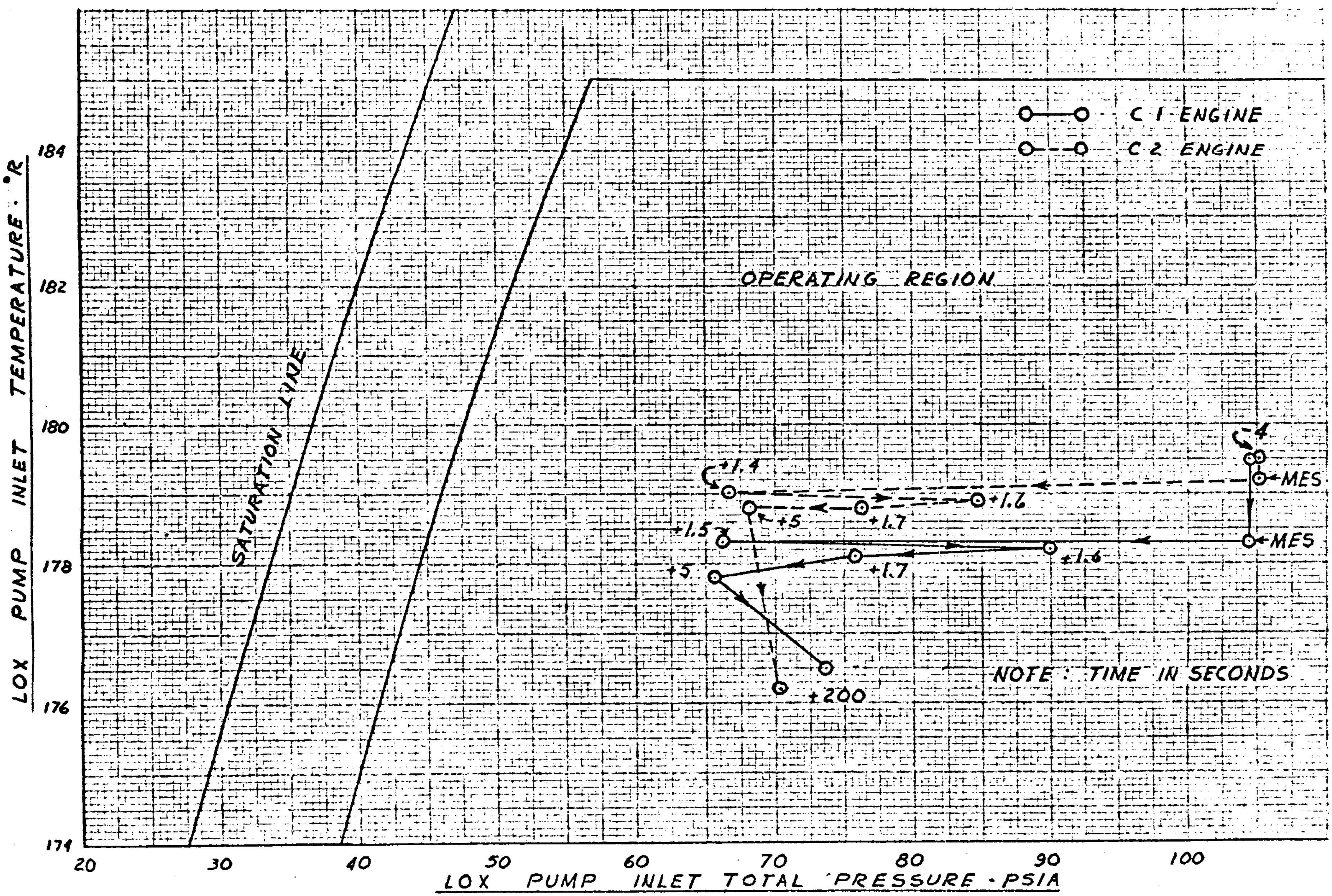


FIGURE 62 PUMP INLET CONDITIONS NEAR ENGINE START FOR THE AC-4 FLIGHT

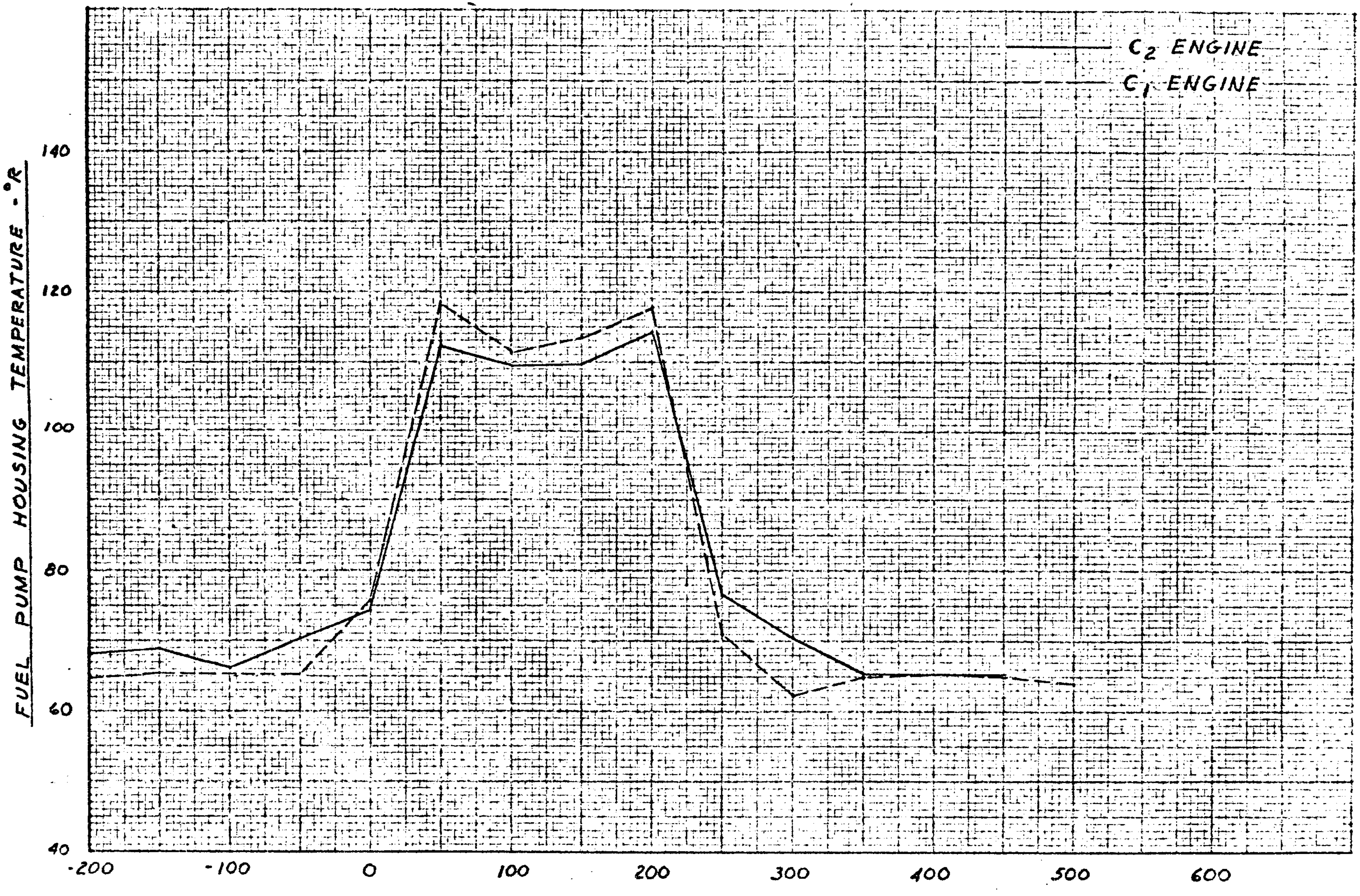


FIGURE 3-3 FUEL PUMP HOUSING TEMPERATURE ON AC-4 FLIGHT

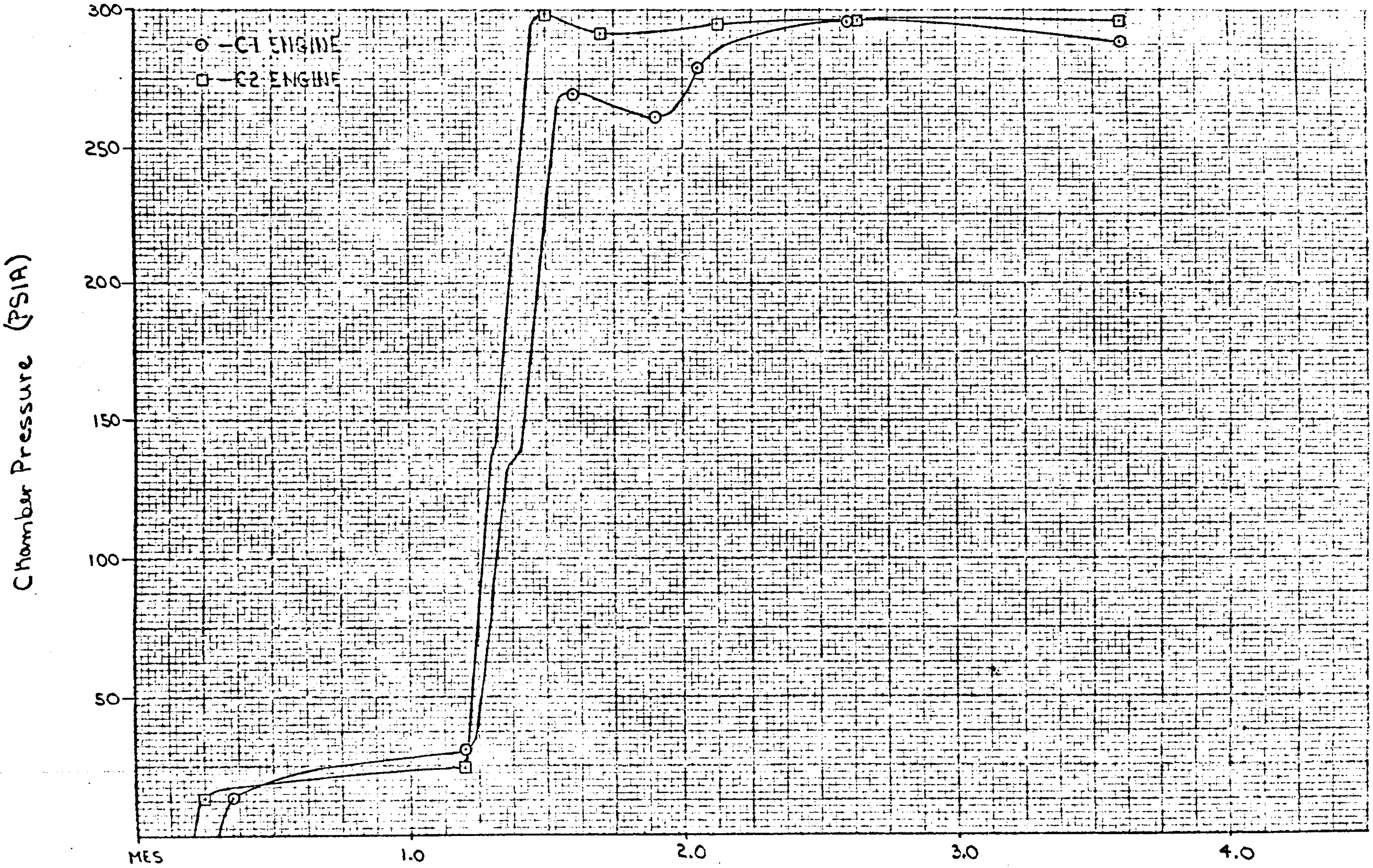


Figure 6-4 Chamber Pressure Start Transient

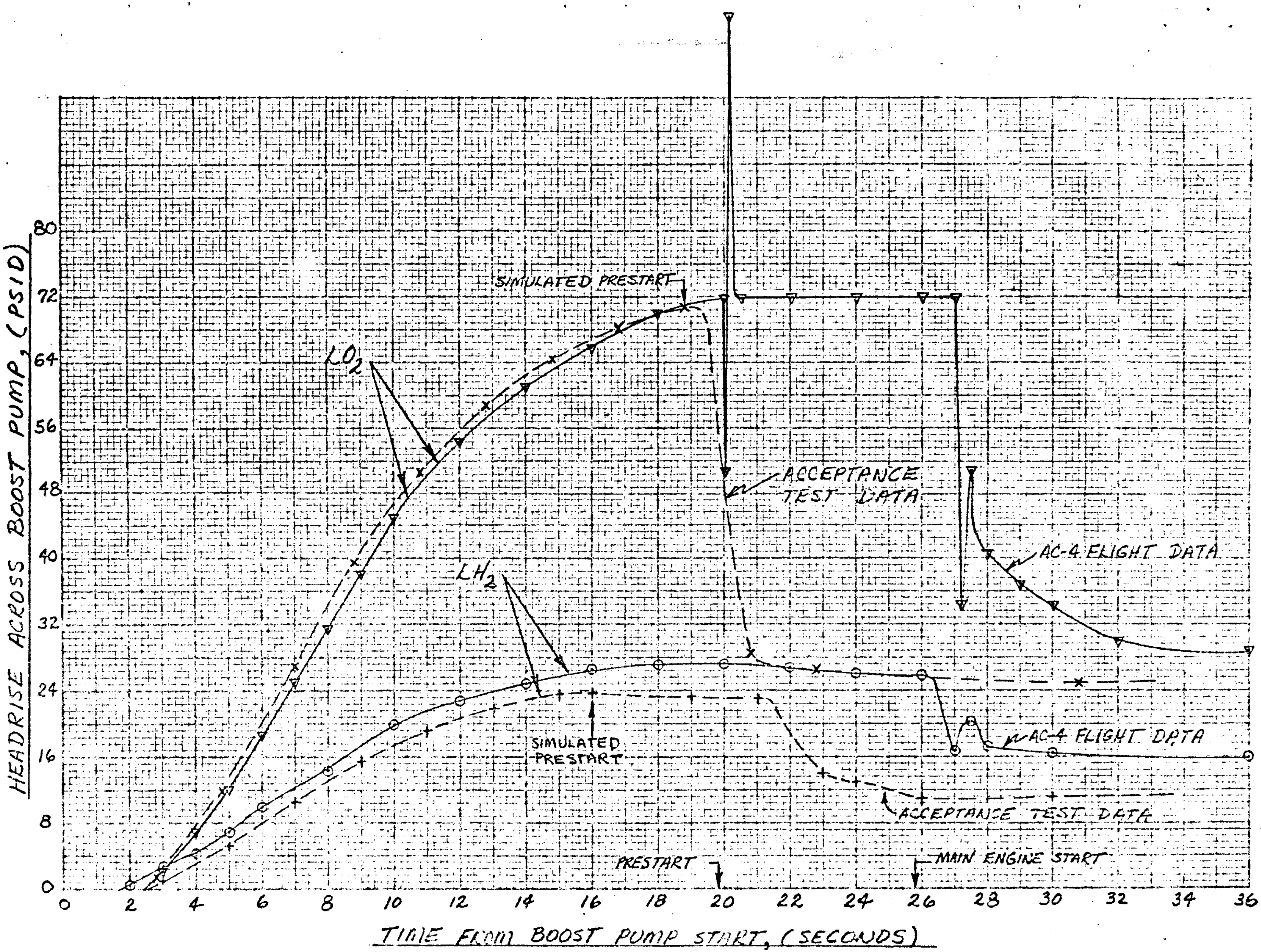


FIGURE 6-5 ; HEADRISE ACROSS CENTAUR BOOST PUMPS DURING ENGINE START TRANSIENT

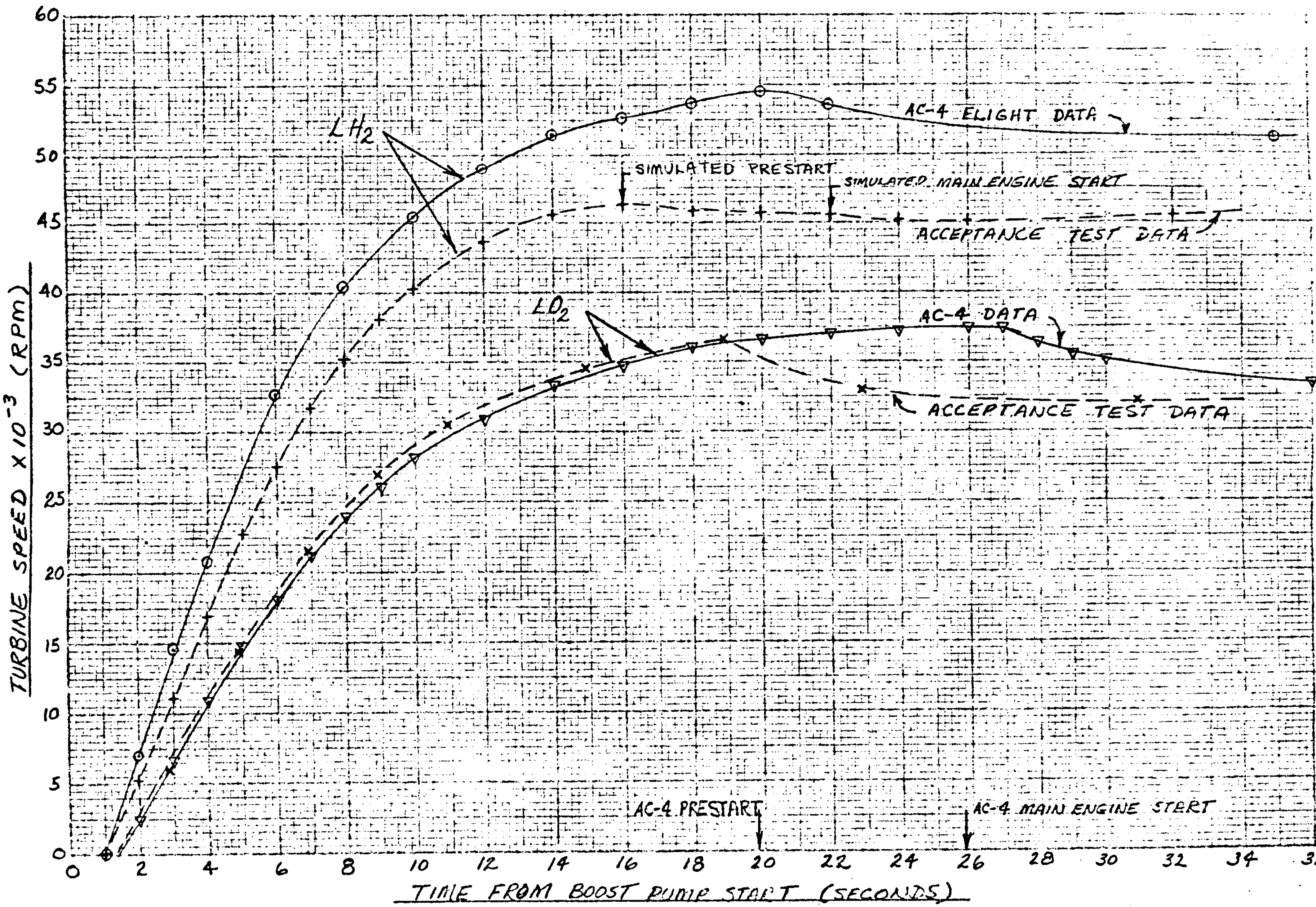


FIGURE 6-6 ; CENTAUR BOOST PUMP TURBINE SPEED DURING ENGINE START TRANSIENT

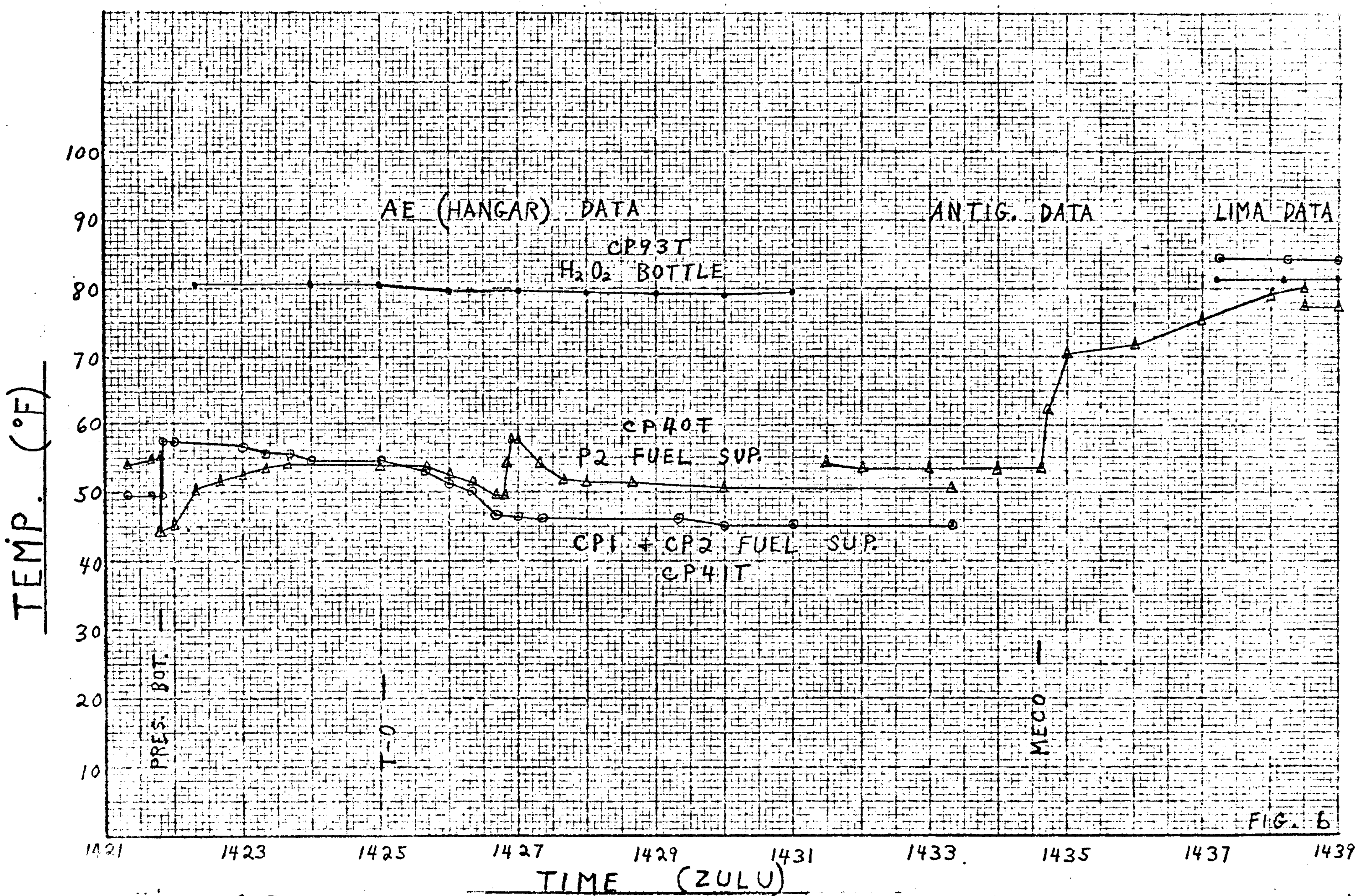


Figure 6-7

H_2O_2 SYSTEM TEMPERATURES

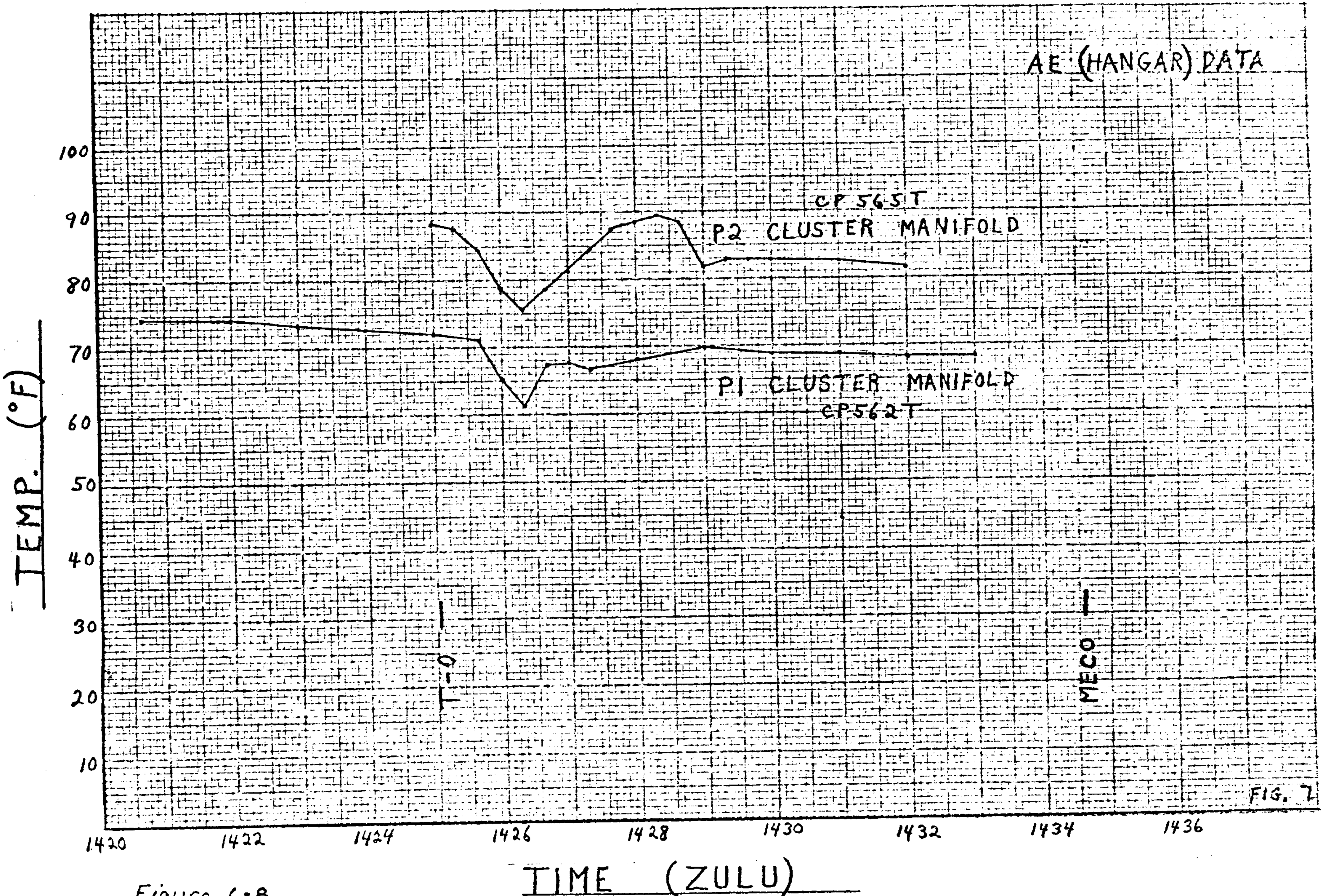


Figure 6-8

ATTITUDE CONTROL SYSTEM TEMPERATURES

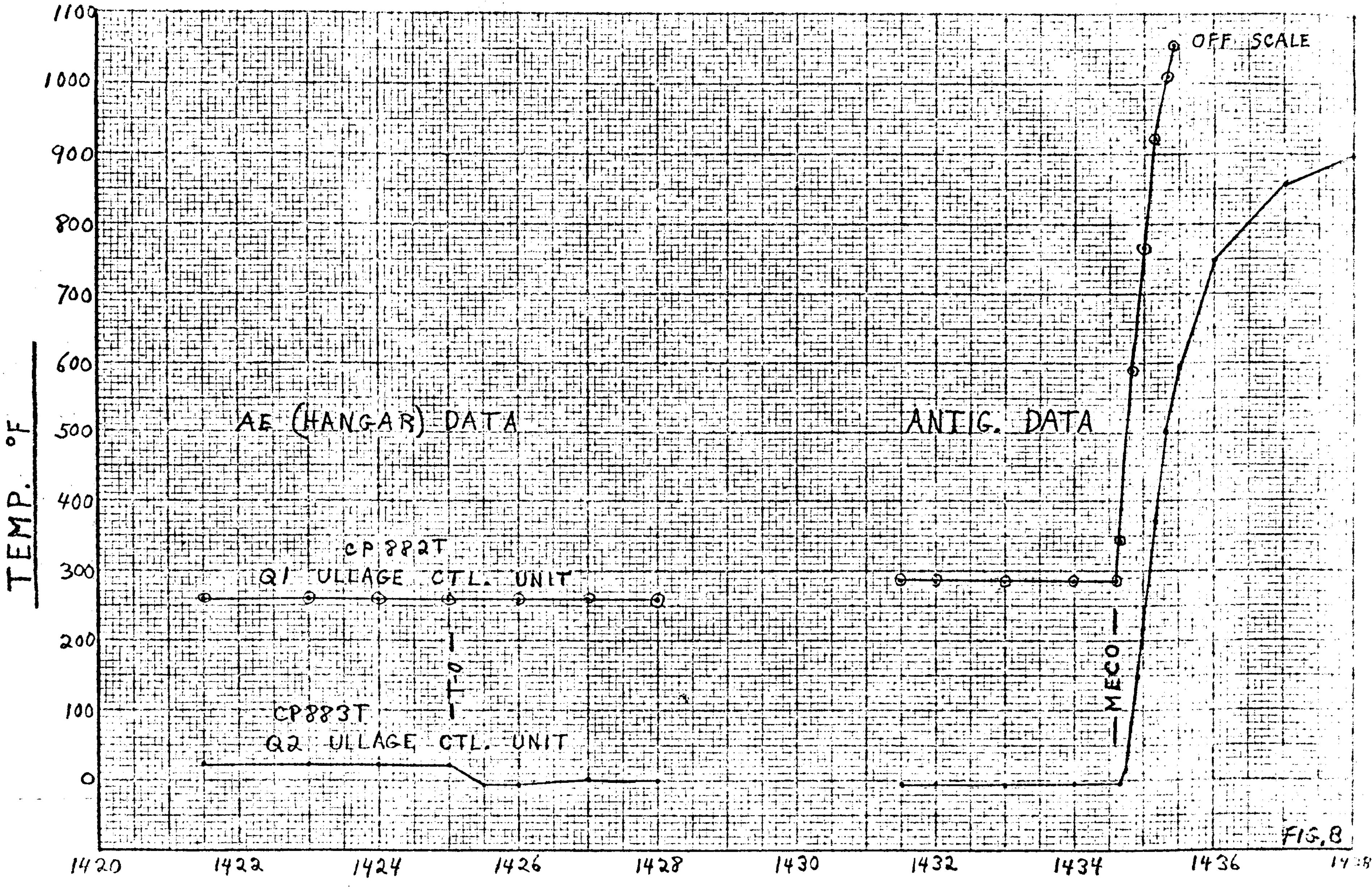


Figure 6-9

ULLAGE ENGINES COMBUSTION CHAMBER TEMP.

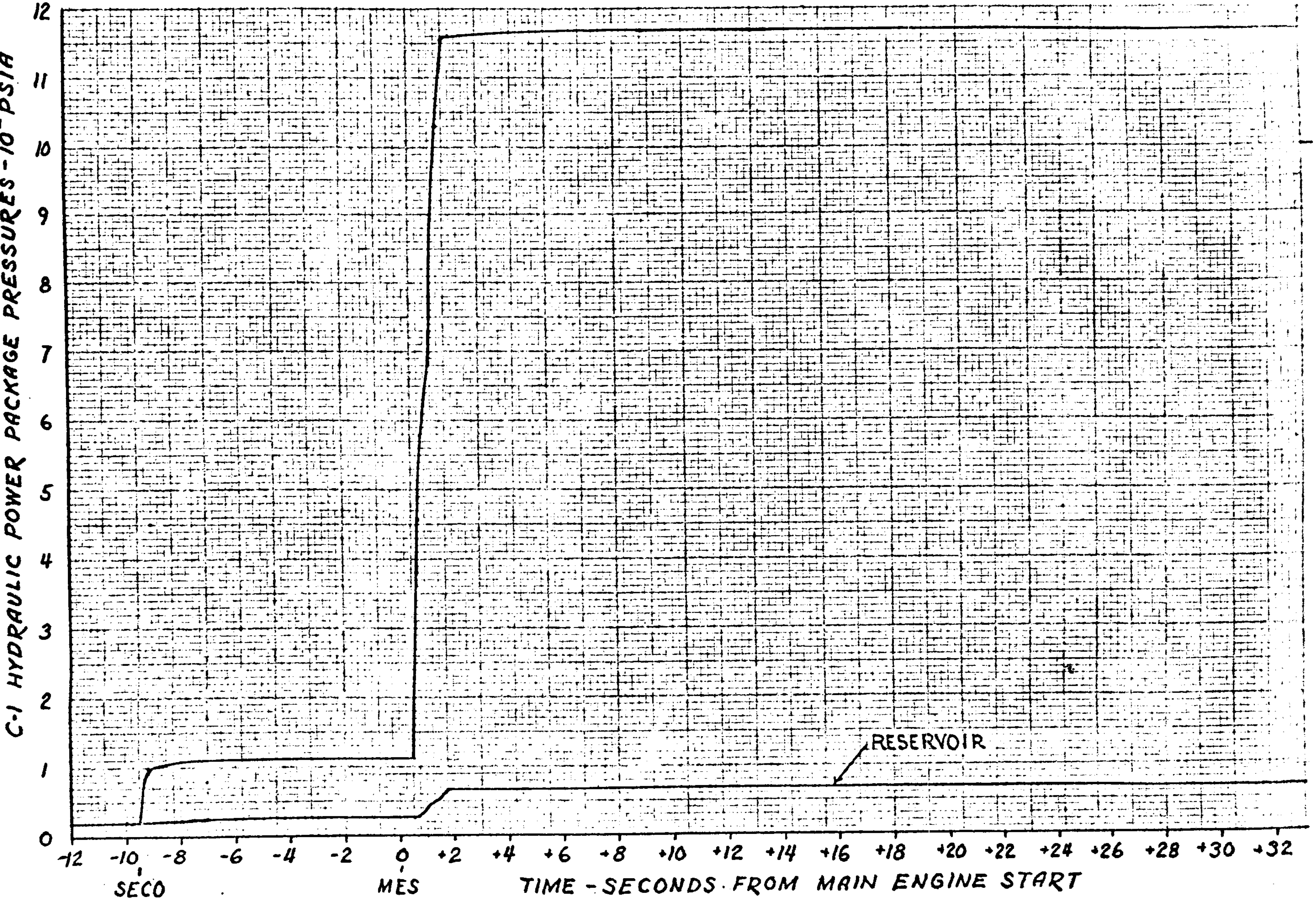


FIGURE G-10 C-1 MAIN & RESERVOIR PRESSURE VS. TIME

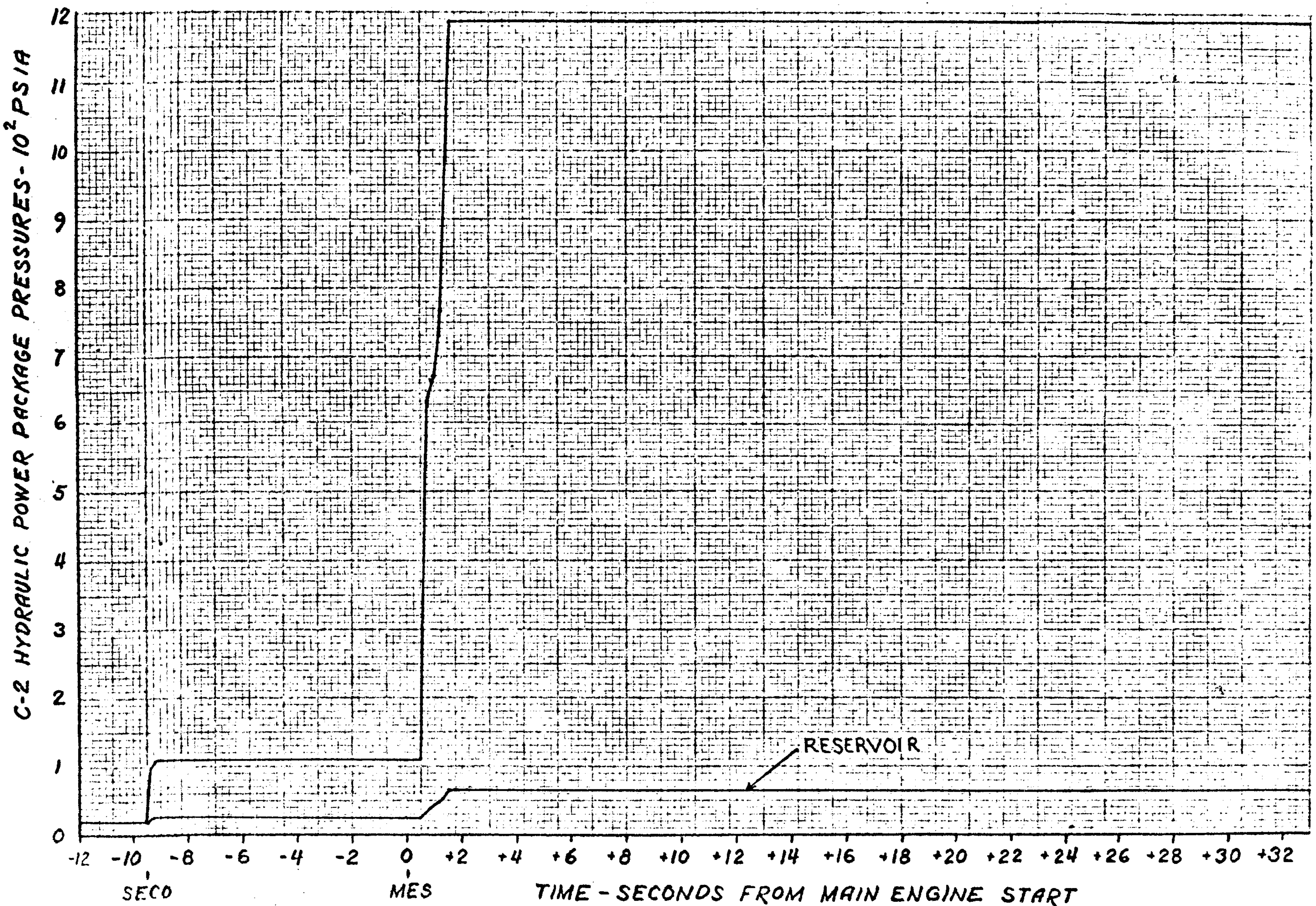


FIGURE 6-11 C-2 MAIN & RESERVOIR PRESSURE VS. TIME

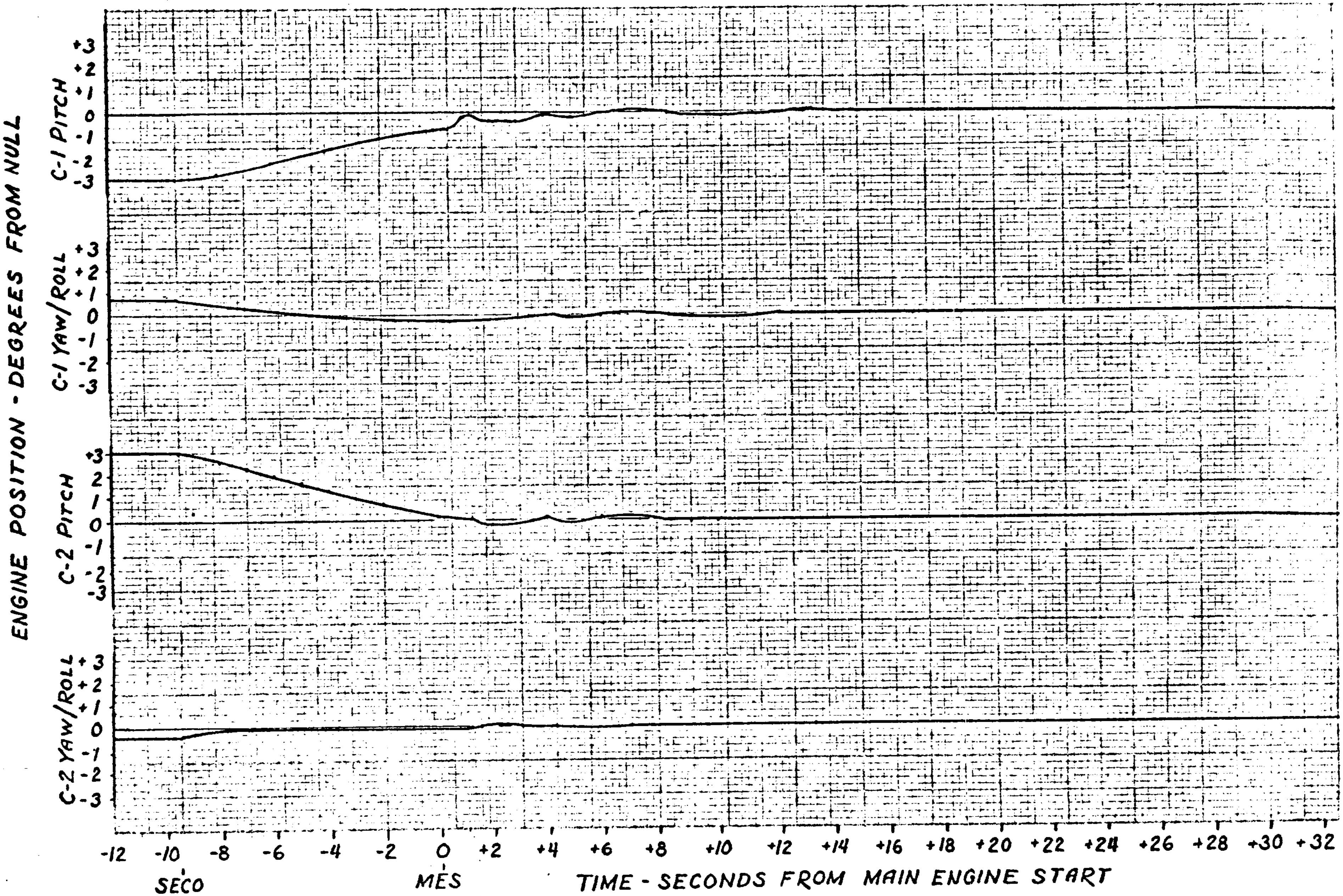


FIGURE 6-12 ENGINE POSITION VS TIME

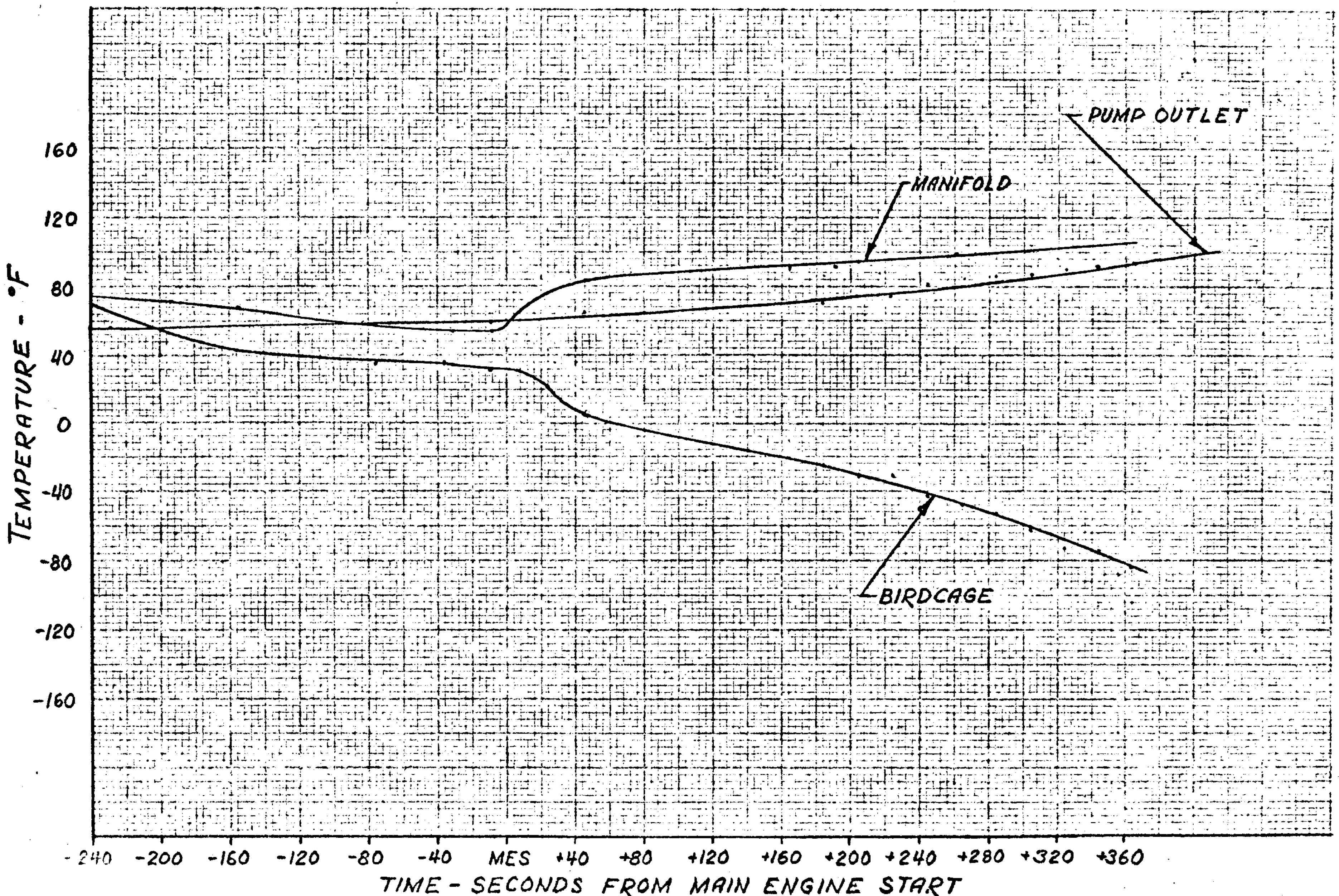


FIGURE 6-13 C-1 HYDRAULIC TEMPERATURES VS. TIME

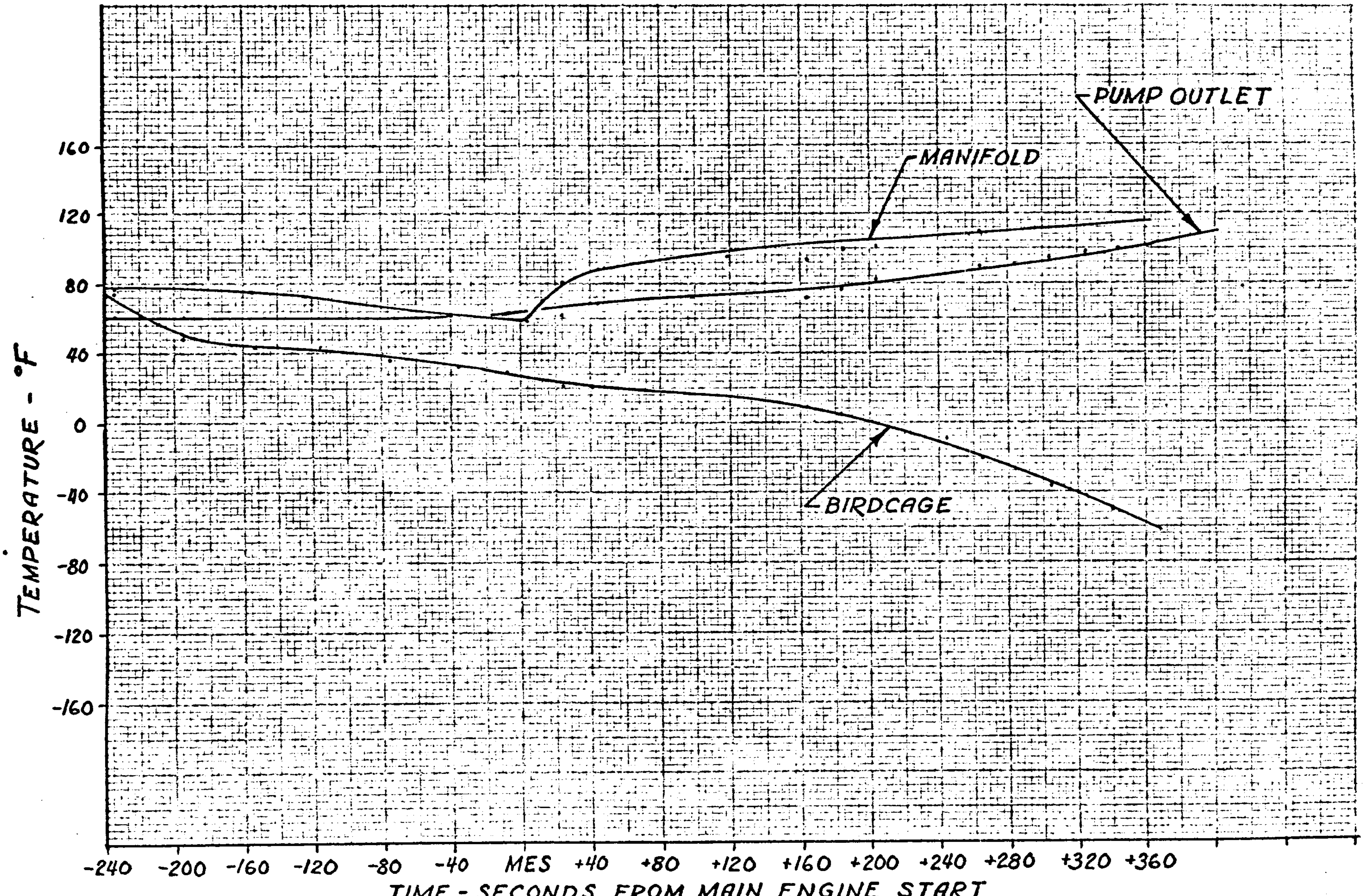


FIGURE 6-14 C-2 HYDRAULIC TEMPERATURES VS. TIME

SECTION 7. CENTAUR PROPELLANT SYSTEMS

SUMMARY

The propellant systems, comprised of the propellant tank pressurization and control, pneumatics system, propellant loading, propellant behavior and hydrogen venting were all generally successful on the AC-4 flight. One exception, however, was the unscheduled forward displacement of the liquid in the hydrogen tank, due to transients following MECO, which upon venting during the coast phase at T + 840 seconds, resulted in a loss of vehicle attitude control.

Tank pressurization and control was normal, vent valves operated within proper pressure limits during powered flight, though a little low during coast phase. This latter apparent discrepancy, however, may have been in the accuracy of resolution of the flight data. Burp pressurization for first and second burn was accomplished without incident; however, a sudden collapse in pressure at second boost pump start is cause for concern and further analysis.

TANK PRESSURIZATION AND CONTROL

The AC-4, LH_2, and LO_2 tank pressures, as shown in Figure 7-1, were adequately maintained within the predicted pressure bands, indicating satisfactory operation of the vent valves and burp pressurization systems. The secondary or number 2 high range vent valve relieved momentarily during the initial lockup period at T + 60.5 seconds. This was due to the higher pressure rise rate experienced during the initial boost period, 4.18 psi per minute compared to 3.53 psi per minute on AC-3. Lockup at BECO and tank burp at MES were normal. Following MECO the primary vent valve was enabled to vent at T + 615 seconds, but it did not relieve until T + 840 seconds, at which time the vehicle lost attitude control. It appears that impingement forces of the expanding vent gases against the forward bulkhead produce a vehicle yaw moment, and attitude control was insufficient for recovery. Tank burp at second MES, T + 2005 seconds, was normal in the LOX and LH_2 tanks, but LH_2 pressure dropped abruptly from 19.5 to 14 psia at boost pump start. This abrupt pressure collapse may have been due to LH_2 spraying into the ullage from the boost pump volute bypass line. Further investigation of this behavior, however, is continuing. A summary of the tank pressures and pressure rise rate data for the flight is given in Table 7-1.

CENTAUR PROPELLANT LOADING

Liquid hydrogen and liquid oxygen were tanked to the planned flight levels on the Centaur stage by the Propellant Level Indicating System (PLIS). In addition to the PLIS, the LOX tank utilized a dual element hot-wire level sensor stationed approximately 1 inch below the planned flight level. It insured that the LOX level at liftoff was above the slosh baffle to prevent sloshing and resulting vehicle instability. A level sensor at the planned flight level was also installed in the hydrogen tank was inoperative during tanking.

The following table summarizes Centaur propellant conditions at liftoff:

	Ullage pressure, psia	Ullage volume, cu ft	Density, lb/cu ft	Station number at liftoff	Volume at liftoff, cu ft	Weight at liftoff, lb
LH_2	20.87	33.94	4.21	184.88	1206.80	5080.8
LOX	31.10	48.30	68.65	381.39	356.30	24,460

PROPELLANT BEHAVIOR

The hydrogen tank on the AC-4 vehicle was extensively instrumented with temperature sensors, along three vertical axes 90° apart, to obtain an indication of propellant behavior during both the powered and coast flight phase. It was the first such attempt on the Centaur vehicle and much valuable data were obtained. A few sensors failed, but for the most part, the sensors yielded valid data on propellant location or liquid level near the tank walls.

Typical temperature profiles throughout the powered and controlled coast phase flight period are shown in Figures 7-2 and 7-3. Sensor response to specific flight events as noted was very distinct. During liftoff the sensors indicated a gradual cooling as the airborne insulation panel purge rate dropped off to zero. A further cooling effect was evident at the time of hydrogen venting. An abrupt increase in temperature was noted simultaneously by all sensors at insulation panel jettison, and, respectively, by each sensor as the liquid level receeded during main engine firing.

At MECO, the sensors above the liquid level showed an abrupt drop in temperature to a liquid indication. It appears that the shutdown transients at MECO, and the discharge of the LH_2 boost pump volute bypass line forward into the ullage, caused a considerable amount of LH_2 to be showered toward the forward bulkhead. Further confirmation of this forward movement is afforded by the forward bulkhead skin temperatures at Station 184 and the ullage gas temperature sensor at Station 162 as shown in Figure 7-4. All three show an abrupt drop to liquid temperatures just after MECO.

A vertical temperature profile in the tank at MECO and MECO + 30 seconds is shown in Figure 7-5. At MECO the temperature distribution gives some indication of a stratified layer near the liquid surface and also in the ullage gas. Thirty seconds after MECO, however, the violent mixing due to engine shutdown transients, markedly changes this temperature profile. Liquid indications existed further up the tank wall and also at the forward bulkhead, while warmer gas temperatures existed around the middle of the tank.

This general distribution with liquid at both ends and gas in the middle continued on into the coast phase and at hydrogen venting as shown in Figure 7-6. This unscheduled liquid distribution was a severe test of the settling rockets performance, and evidence of liquid at the forward end during venting, after 268 seconds of oriented coast flight, indicates a deficiency. There were some possible indications that the LH_2 tank near the upper stations showed some slight warming trends before venting, but not sufficient to indicate the absence of liquid. Additional analysis is necessary before this problem can be resolved.

Upon venting at T + 840 seconds, the vehicle began to tumble in yaw, and never regained attitude control. It appears that excessive venting rates caused by liquid or liquid entrainment, produced excessive impingement forces against the forward bulkhead resulting in induced yawing moments greater than could be cancelled out by the attitude control engines.

The yawing motion was further aggravated by the settling rockets. The forward movement of the liquid in the tank resulted in a more forward cg, such that the firing of the ullage rockets also induced a yawing moment in the same positive direction. This action is confirmed by the attitude engine firing signals, which showed a uniformly on-off pattern from MECO to hydrogen venting at T + 840 seconds. At venting, attitude control engines fired continuously but were unable to correct the yaw motion.

From LH_2 venting onward, the contrifugal force, due to the tumbling, forced the LH_2 toward the forward end of the tank. Hence, a lack of sufficient liquid head at second MES resulted in boost pump starvation and failure to achieve the second burn mission.

The most interesting results of the temperature sensor data, however, were the marked indications of liquid level during Centaur main engine firing. Each sensor indicated an abrupt rise in temperature with the passage of the liquid level. Correlating these wet to dry indications it was possible to establish the variation of liquid level with time as shown in Figure 7-7. The correlation was excellent, and as shown the liquid level at MECO can be accurately established at Station 339.

HYDROGEN VENTING

The hydrogen venting schedule on AC-4 was revised slightly from AC-3. The initial primary vent valve lockup period extended from T - 7 to T + 74 seconds, and the primary vent valve was enabled after MECO at T + 615 seconds. First venting, however, occurred prior to the programmed 74-second unlock, as the secondary valve cracked momentarily at T + 60.5 seconds. The scheduled venting after 74 seconds and after BECO was accomplished without incident, and the flow rates, as shown in Figure 7-8, were about the same as on the AC-3 flight. Preliminary results indicate that about 44 pounds of hydrogen were vented prior to BECO, and 28 more pounds were vented after BECO and prior to MES.

The coast phase venting, however, was not normal. Enabling of the primary vent valve at T + 615 seconds allowed venting to occur as soon as the tank pressure reached the cracking pressure of the valve, and this occurred at T + 840 seconds, after 267 seconds of near zero g coasting. The presence of liquid at the forward end of the tank at the time of vent opening, as discussed earlier, resulted in liquid entrainment and excessive venting flow rates. The nonpropulsive vent apparently controlled in the normal venting thrust axis, but severe impingement forces normal to the vent axes, produced yawing moments in excess of the restoring capability of the attitude control engines and the vehicle began to tumble.

The venting flow rates during this coast phase period are shown in Figure 7-9. Flow rates are shown for both gas and liquid states, based on the measured Venturi pressures. The Venturi temperature data indicated gas venting for the first 2 seconds, but then fell rapidly to a saturation temperature. The vent valve definitely cycles and during the first three reseat periods, the Venturi temperature actually warmed up slightly indicating the presence of some gas. After this period the Venturi temperature remained saturated, even when the vent valve was seated, indicating the presence of liquid in the duct. Pressure spikes, particularly during the first few vent cycles, indicating high flow rates, may have been caused by liquid flashing off in the warm vent duct. In spite of the liquid entrainment, and/or liquid venting, tank pressures remained stable and within specified limits.

TABLE 7-1

SUMMARY OF PROPELLANT TANK PRESSURES

Event and time	Tank	Initial pressure, psia	Final pressure, psia	ΔP, psi	Average pressure rise rate, psi/min
Initial vent valve lockup T-7 to T + 60.5 when number 2 valve relieved	LH_2	20.8	25.5	4.7	4.18
	LO_2	31.1	30.4	---	------
BECO lockup T + 148 to T + 157.5	LH_2	19.2	21	1.8	11.35
	LO_2	29.8	29.7		
Tank burp at MES T + 224	LH_2	18.5	19.4	.9	------
	LO_2	29.4	33.1	3.7	------
Main engine cutoff T + 576	LH_2	16.2	----	---	------
	LO_2	27.9	----	---	------
Coast phase T + 576 to T + 840	LH_2	16.2	19	2.8	.646
	LO_2	28.2	29.5	1.3	.295
Tank burp at second MES T + 2005	LH_2	18.9	19.5	.6	------
	LO_2	31.4	34.0	2.6	

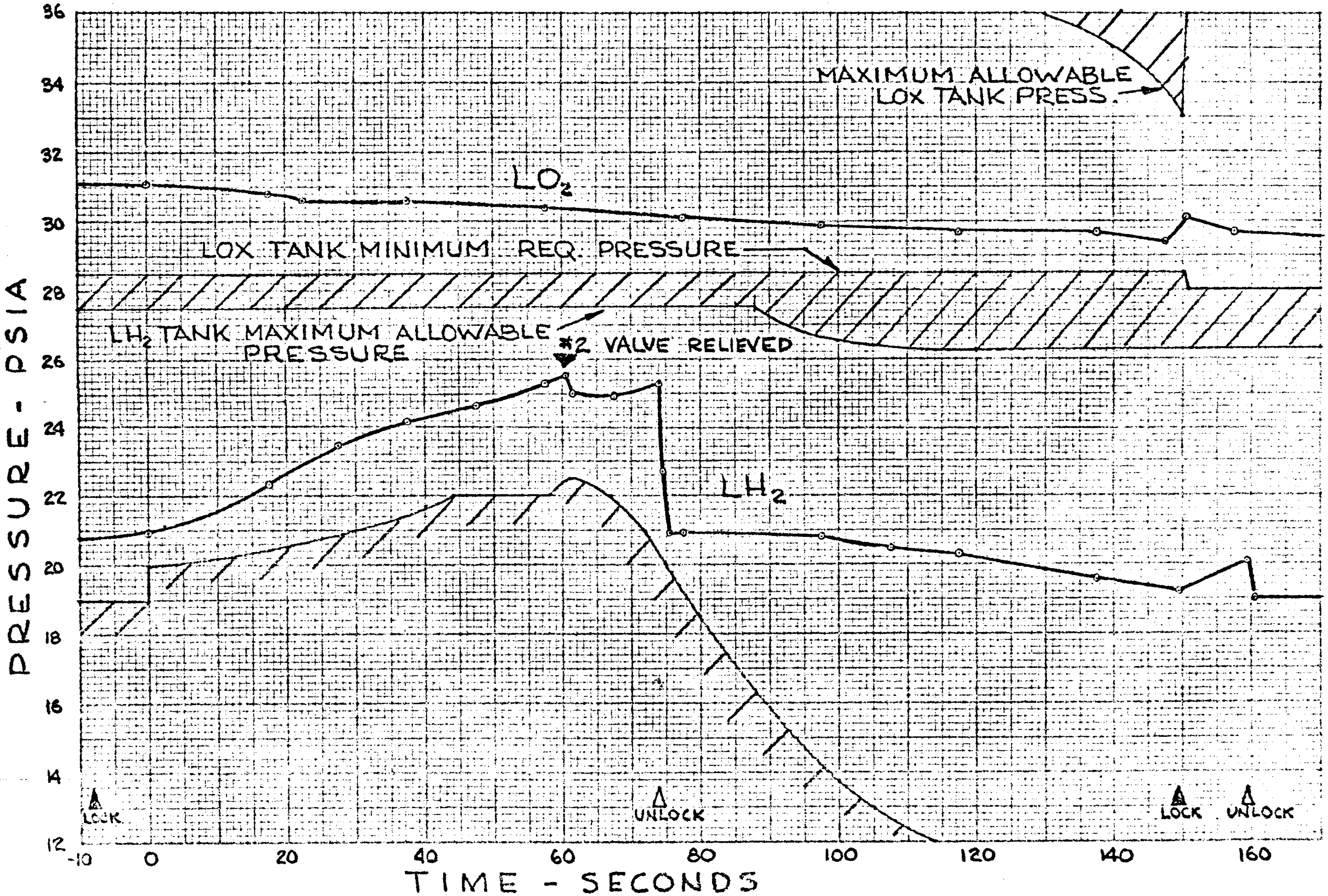


FIG. NO 7-1A AC-4 LO_2 & LH_2 TANK PRESSURES

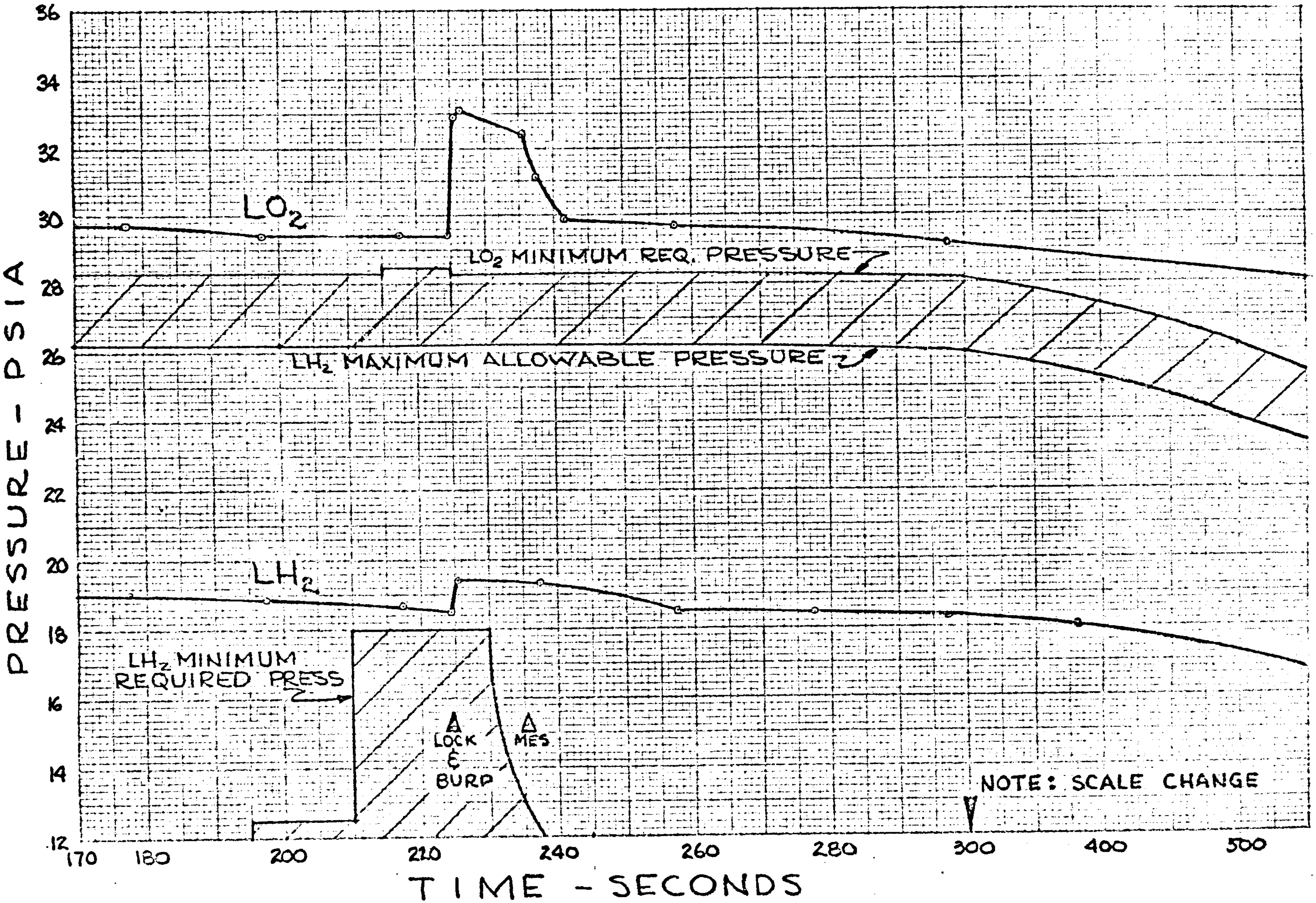


FIG NO 7-1B AC-4 LO_2 & LH_2 TANK PRESSURES

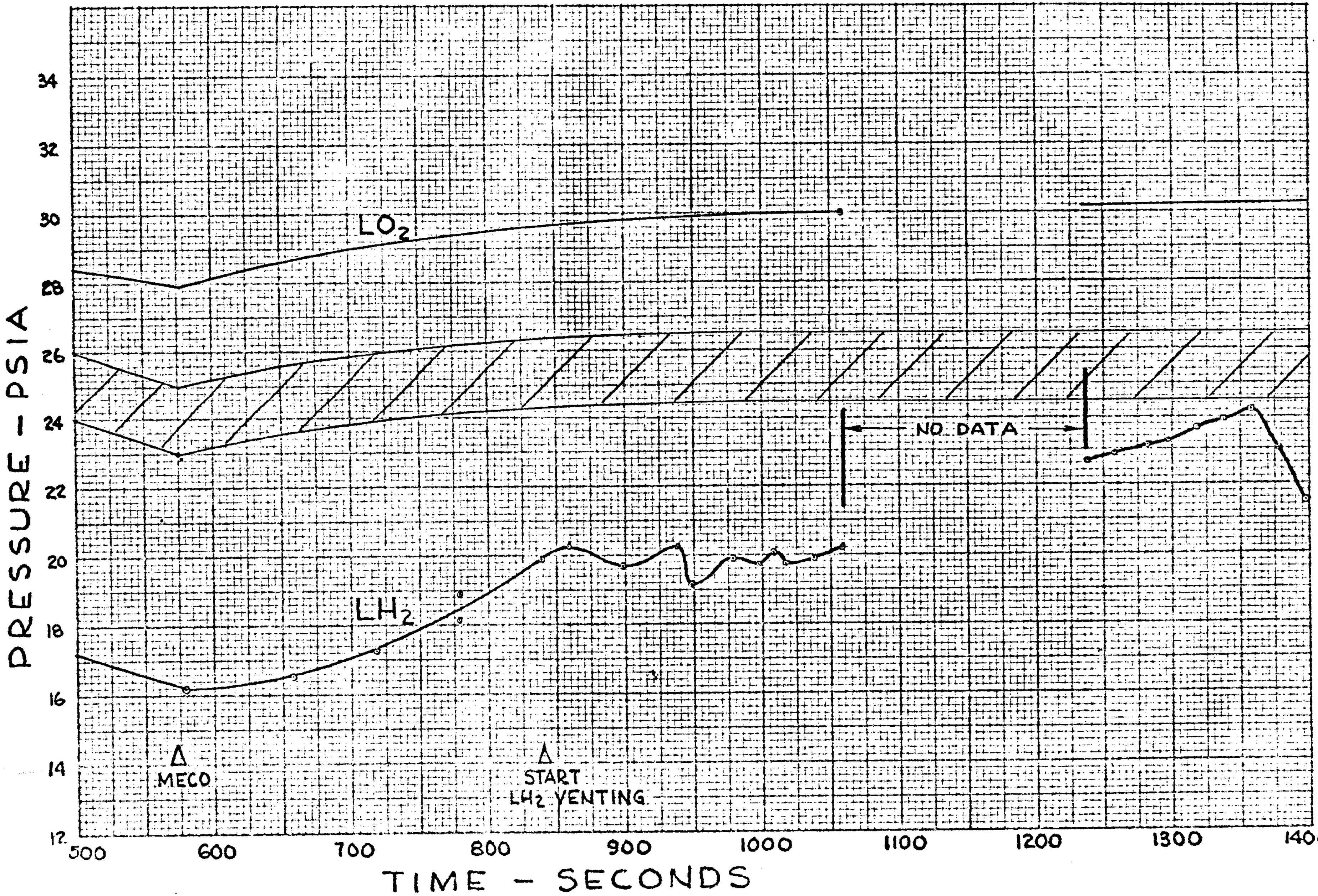


FIGURE 7-1C AC-4 LO_2 & LH_2 TANK PRESSURES

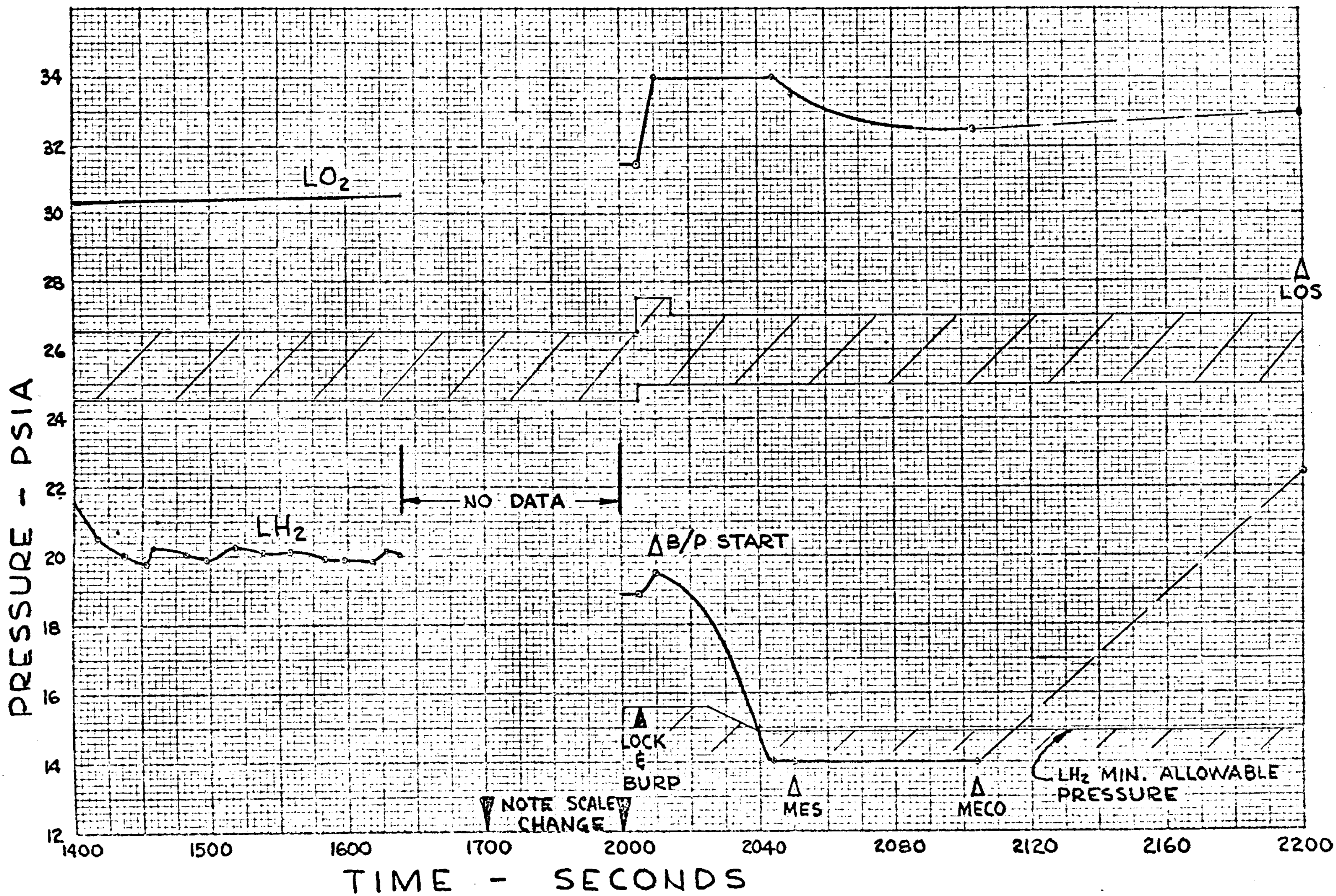


FIGURE 7-1D AC-4 LO_2 & LH_2 TANK PRESSURES

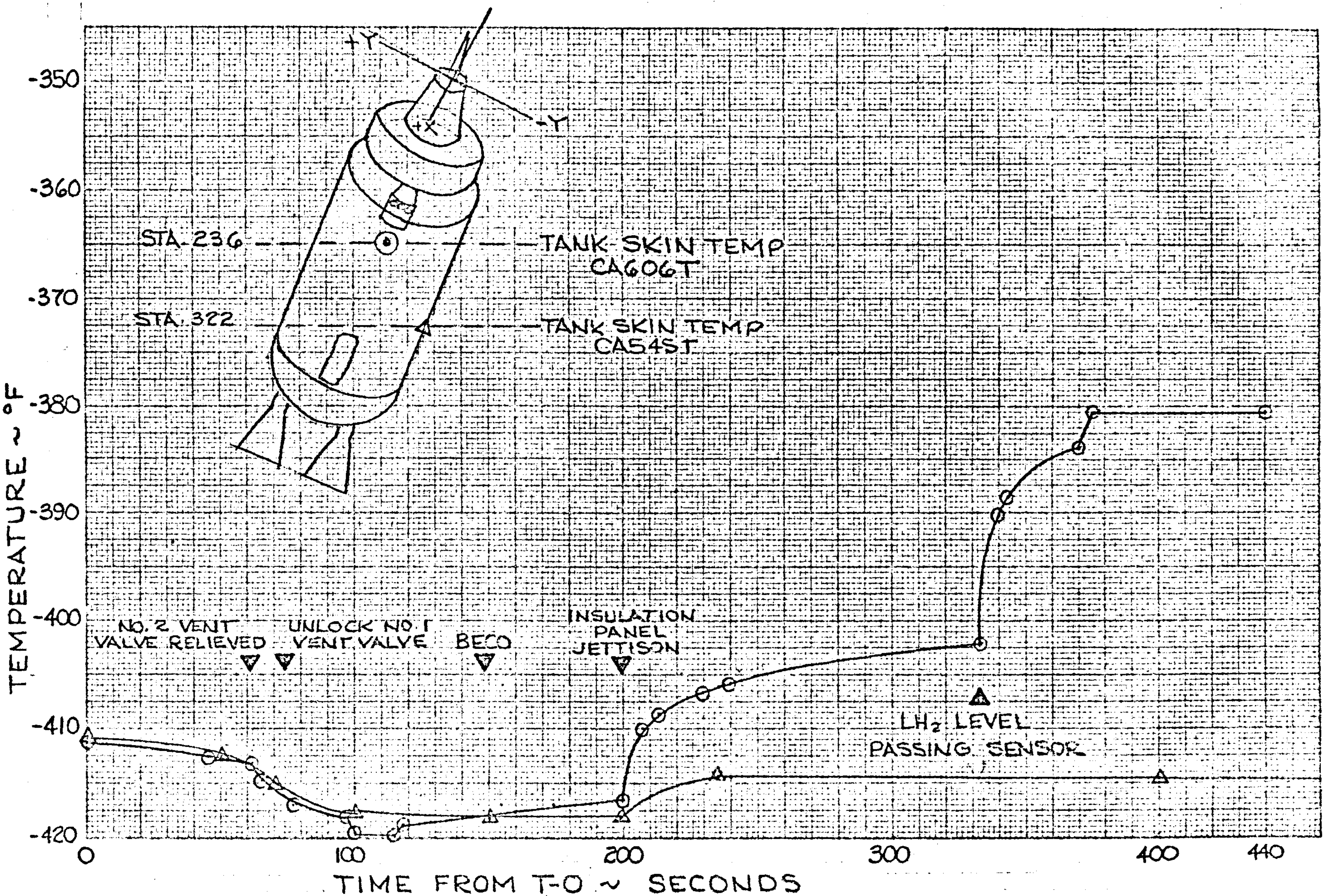


FIG NO. 7-2 A TYPICAL TANK SKIN TEMPERATURE HISTORY

SHEET 1/2

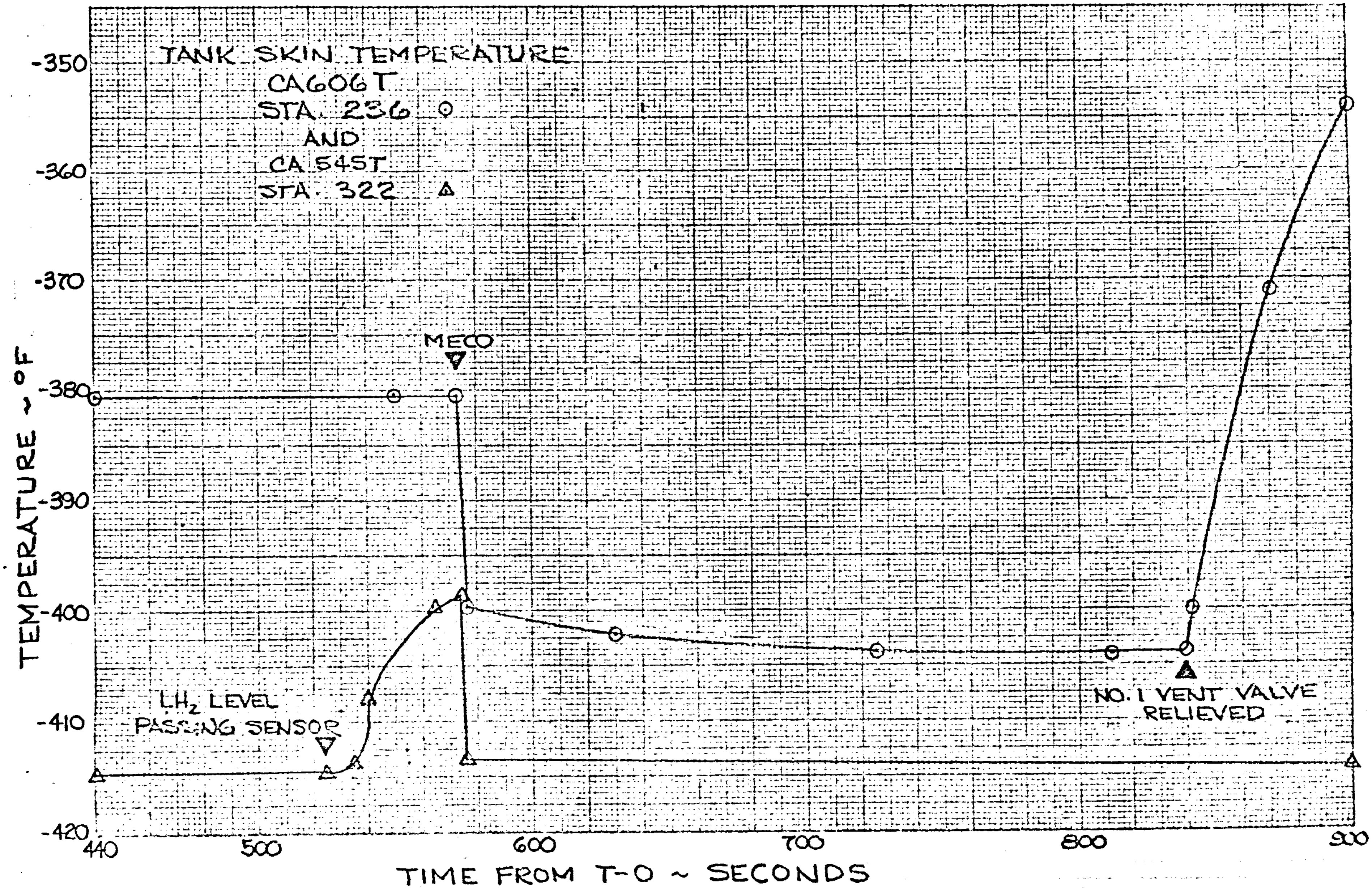


FIG NO 7-2B TYPICAL TANK SKIN TEMPERATURE HISTORY

SHEET 2/2

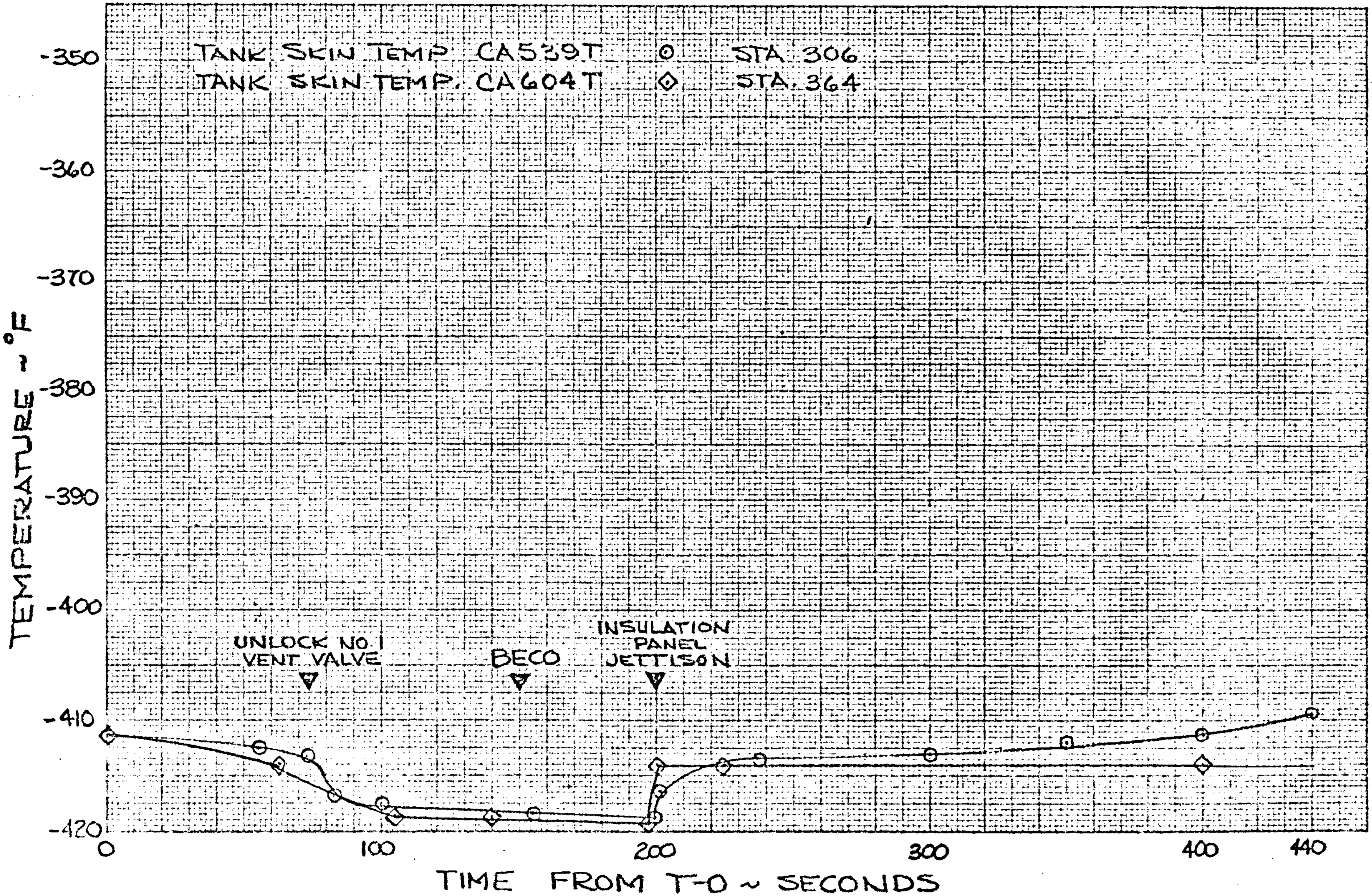


FIG NO 7-3A TYPICAL TANK SKIN TEMPERATURE HISTORY

SHEET 1/2

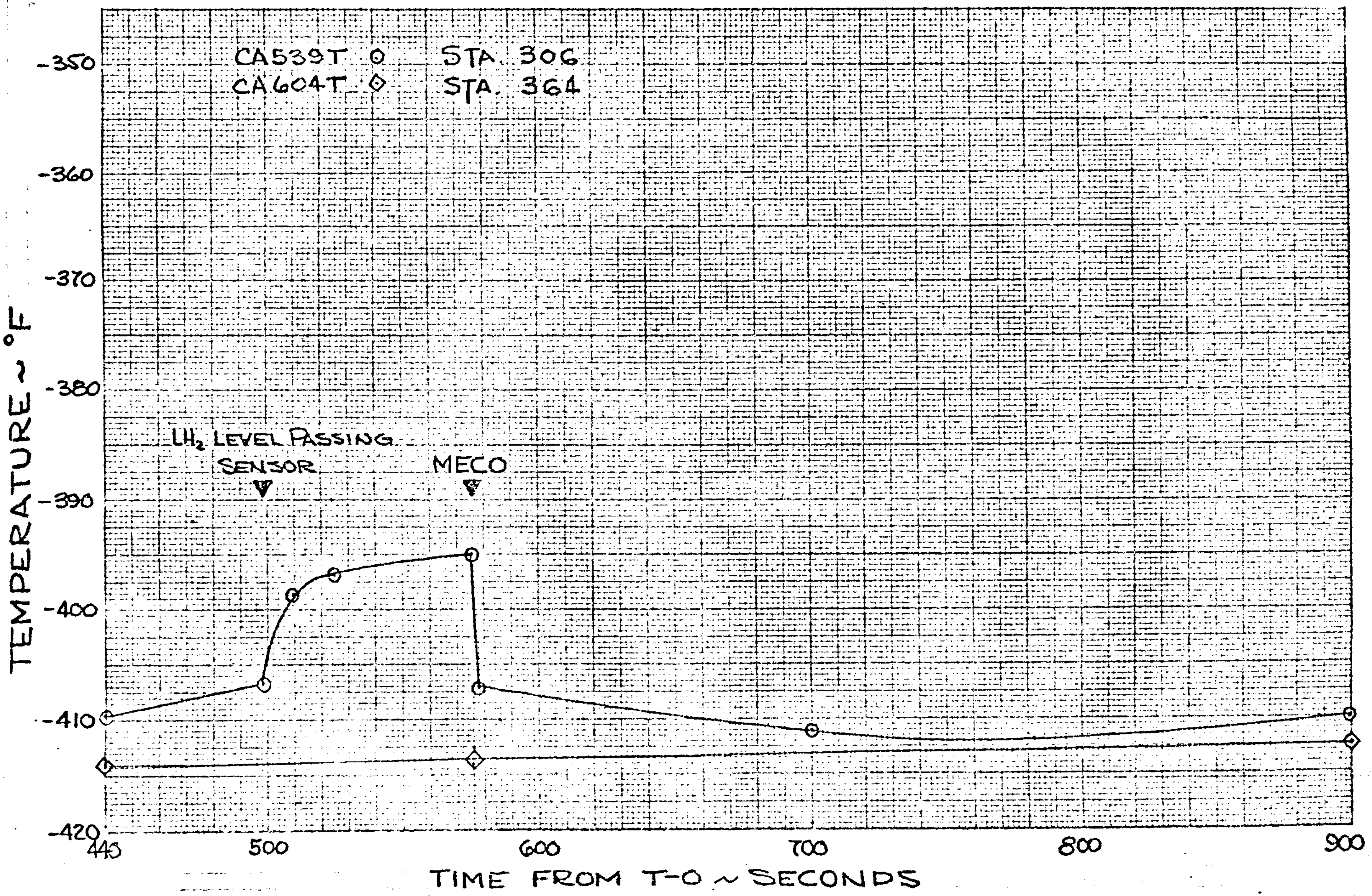


FIG. NO. 7-3B TYPICAL TANK SKIN TEMPERATURE HISTORY

SHEET 2/2

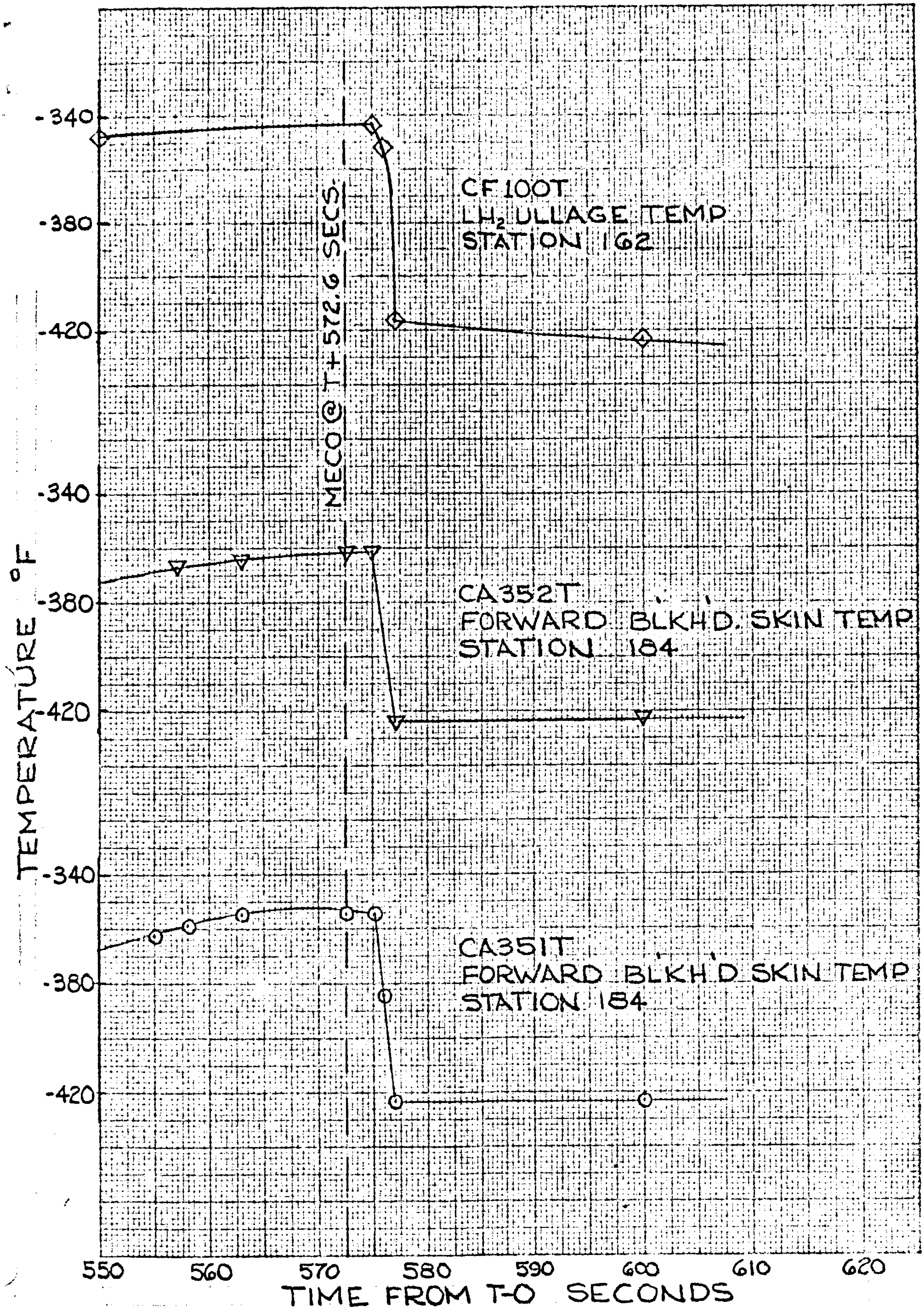


FIG. NO 7-4 TEMP. HISTORY NEAR MECO - FORWARD BULKHEAD AREA

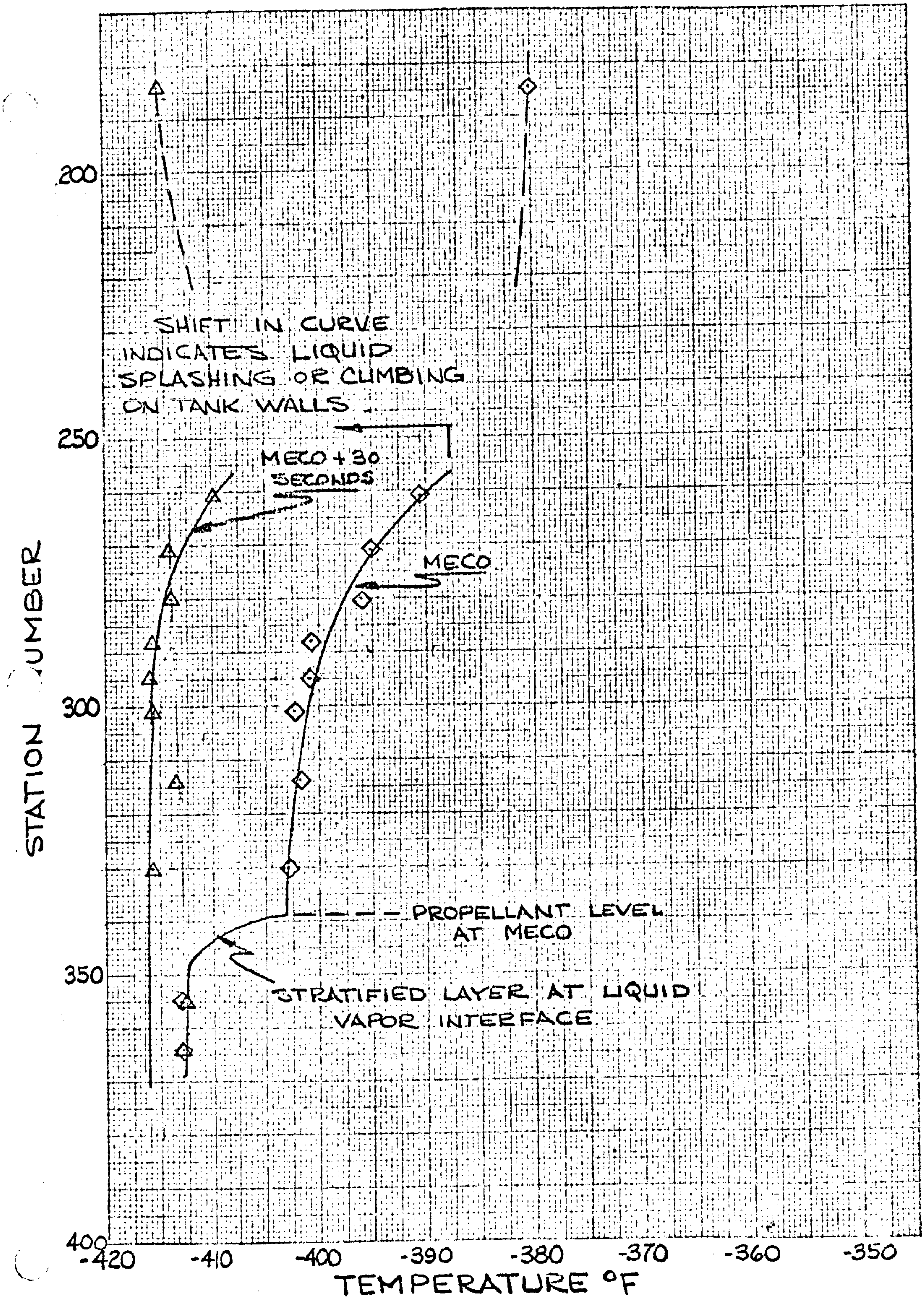


FIG NO. 7-5 LH_2 TANK TEMPERATURE PROFILE AT MECO AND MECO + 30 SECONDS.

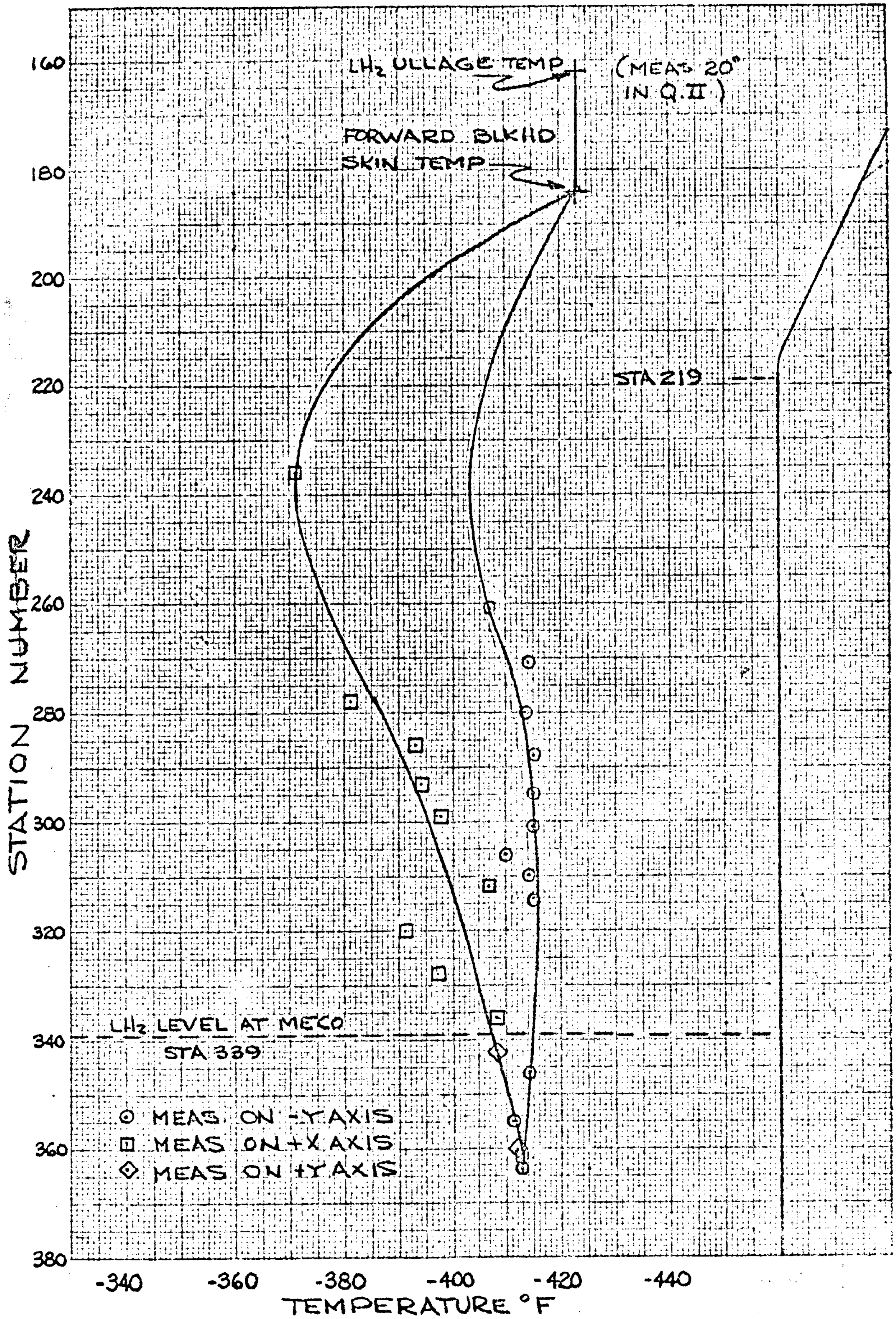


FIG. NO. 7-6 LH_2 TANK TEMPERATURE PROFILE AT 1ST HYDROGEN VENT DURING COAST

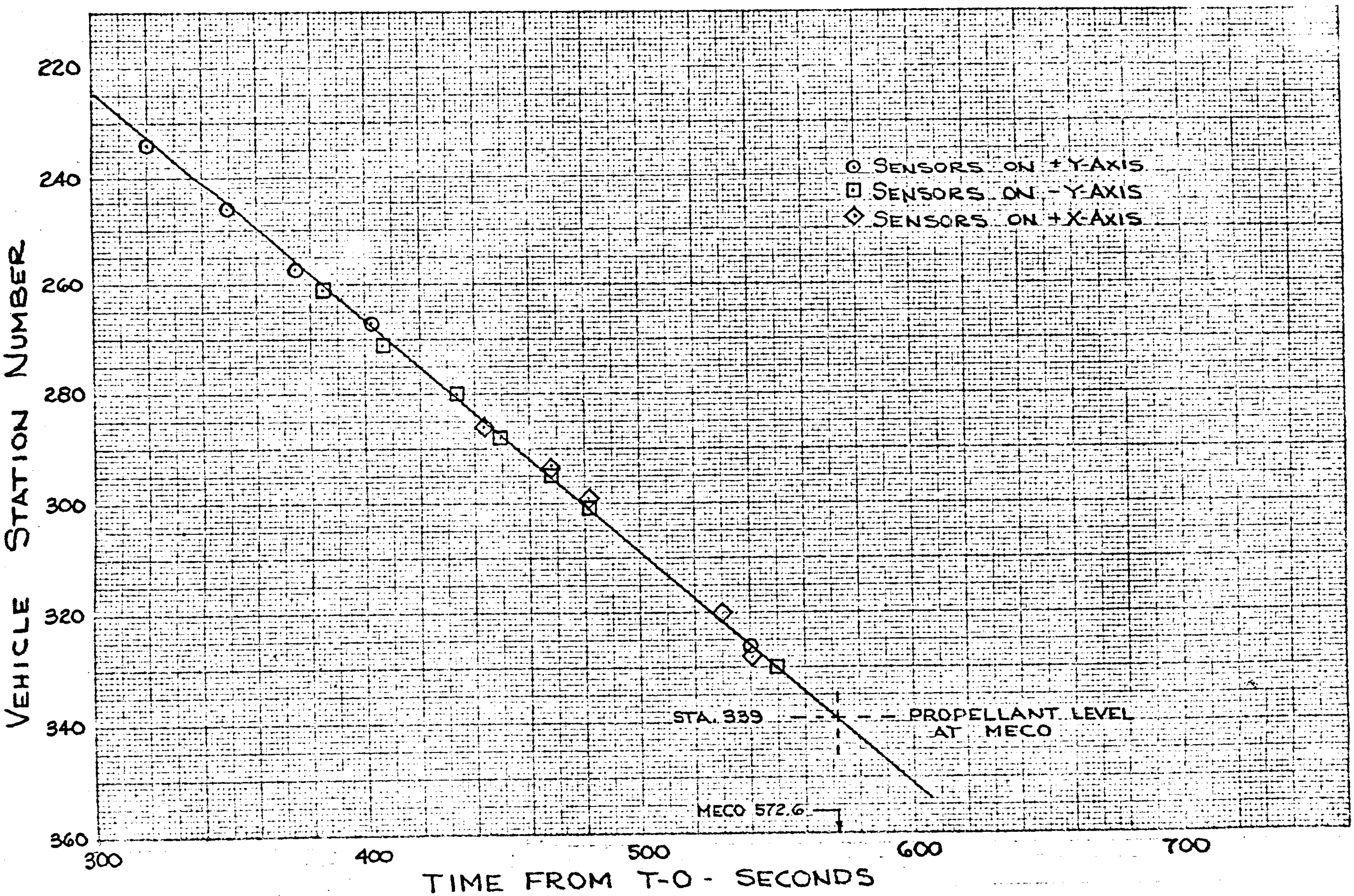


FIG. No 7-7 LH_2 Liquid Level vs. Time - Tank Skin Temperature Data

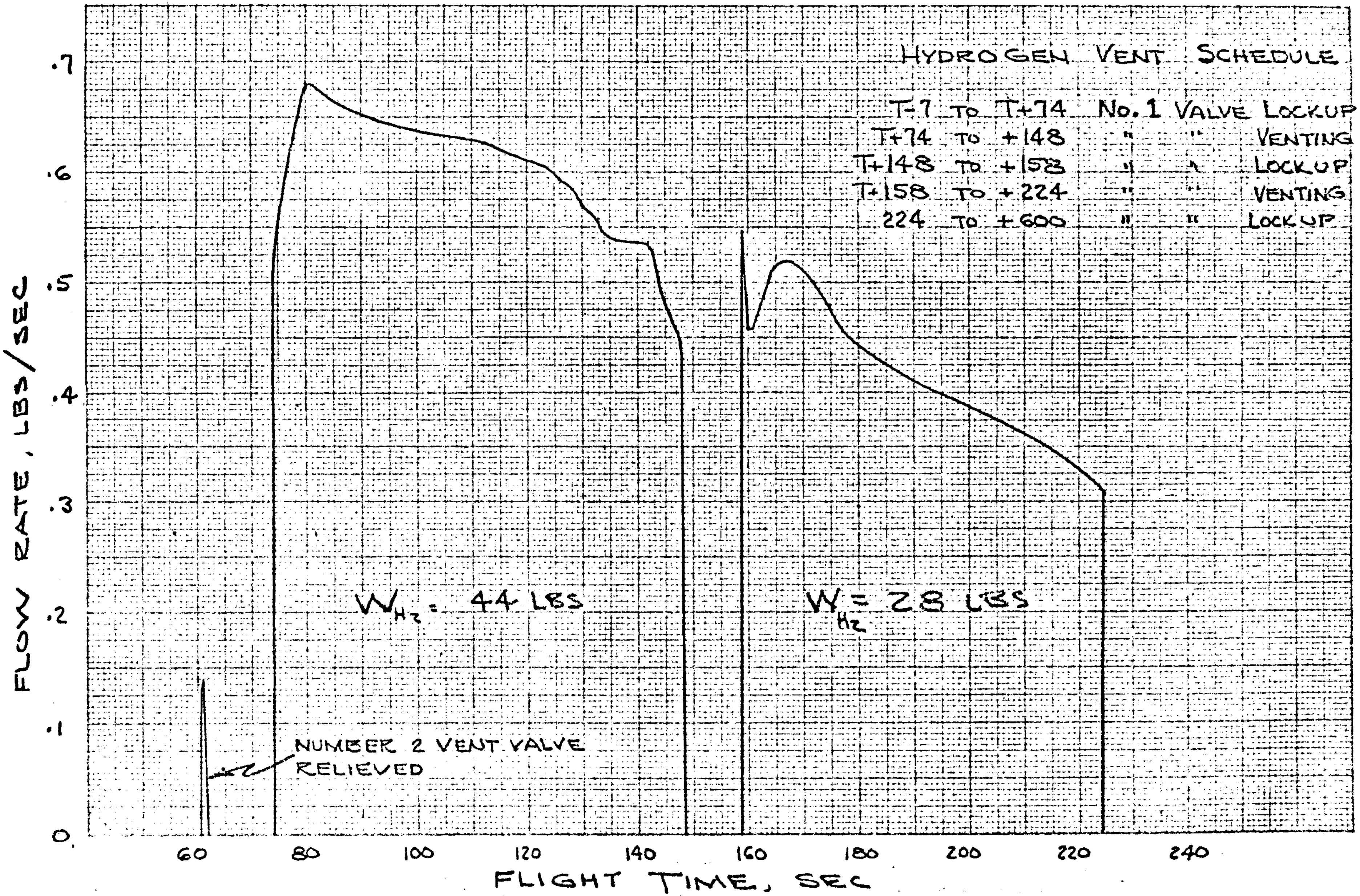


FIGURE 7-8 HYDROGEN VENTING FLOW RATE

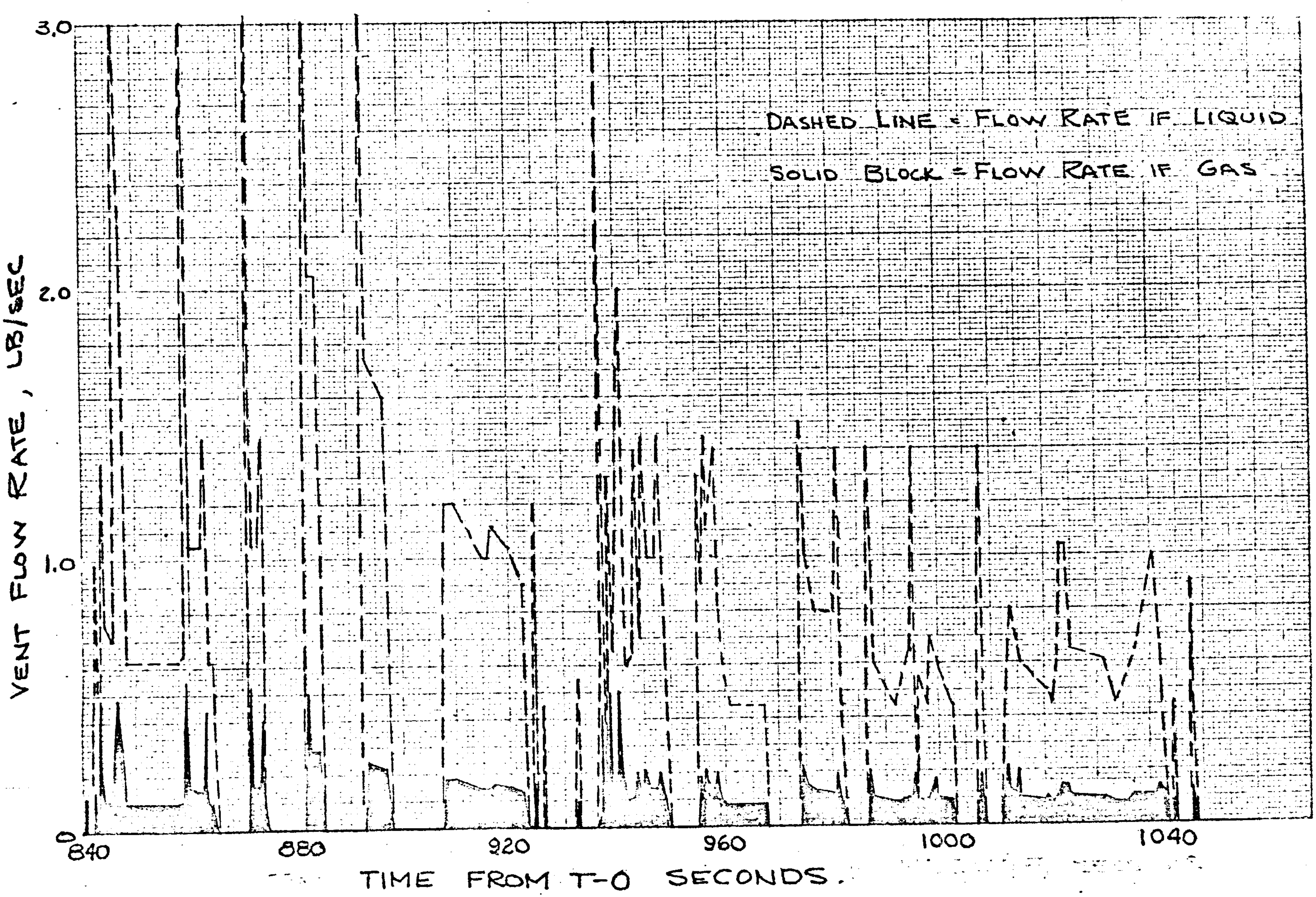


FIGURE 7-9 COAST PHASE HYDROGEN VENTING RATES

SECTION 8. SEPARATION

SUMMARY

The separation systems on the AC-4 flight consisted of (1) the insulation panels, (2) the nose fairing, and (3) the Atlas booster stage. The successful jettisoning of the insulation panels and the nose fairings made up one of the primary flight objectives and the operation of the staging system was a secondary objective.

The three systems performed as designed with no anomalies being noted. Subsequent to the AC-3 flight, tests of the nose fairing separation system were conducted at Lewis Research Center in an effort to determine the cause of, and effect a remedy for, shocks to the guidance system which were noted on that flight. These shocks were coincident with nose fairing jettison and it was felt this event was their cause. As a result of the test series, modifications were made to the system and no guidance system disturbances were noted on AC-4.

Vehicle stating occurred normally with only a low level of angular motion of the Atlas noted during the separation interval.

As a result of the AC-4 flight, the level of confidence in the three separation systems has been increased.

INSULATION PANEL SEPARATION

Breakwires were located on the insulation panel jettison hinges to record panel jettison. These measurements were listed as AA401X, AA402X, AA403X, and AA404X. They were strictly an "off-on" type of measurement. From these measurements it can be concluded that all the panels were jettisoned simultaneously at T + 198.55 seconds. This was also verified by checking the panel instrumentation. It can be clearly seen by looking at the raw data that the instrumentation ceased to function at T + 198.55 which would indicate that the panels had separated from the vehicle. When the panels are jettisoned the instrumentation is cut off by means of an instrumentation disconnect in the area of the "wedding band." This disconnect will not function until the panels have almost completely separated. Another check was made by looking at the tank strain gage data. A definite increase in tank hopp strain was observed at the time of panel jettison. This indicates that there was an interference pressure between the panels and the tank prior to jettison and at the time of jettison the pressure ceased which indicates the panels had separated.

From all of this data it can be concluded without doubt that the insulation panels had parted simultaneously at approximately T + 198.55 seconds which was the planned jettison time.

NOSE FAIRING SEPARATION

Nose fairing separation was accomplished successfully with none of the indications of malfunction seen in the AC-3 flight. Since the nose fairing flight qualification tests run at Lewis used many of the flight transducers, a comparison of flight data with Lewis test data is given in this report.

Pressure in the thruster bottle cavity as indicated by CA445P was 9.20 pounds per square inch absolute as compared with 4.9 psia on Lewis test data using the same transducer. Two other Lewis test transducers were used in the flight qualification tests. Transducer number 29 was located beside CA445P and received pressure along the X-axis as did CA445P.

This transdufer read 8 psia. Transducer 42 was located at the intersection of the bulkhead and the nose fairing on the YY-axis and read pressure along the Z-axis. It read 16.0 psia for the Lewis tests. Pressure on the top of the Surveyor mass model was read by CY102P and pressure at the base of the model was shown by CY101P. CY102P indicated 0.081 psia for the flight and 0.070 psia for the Lewis tests. CY101P indicated 0.087 for the flight and 0.070 for the Lewis tests.

Acceleration was read at the mass model base by CY710 and the X-direction and CY720 in the Y-direction and was read at the mass model top by CY740 in the X-direction and CY-750 in the Y-direction. The flight data for these pickups never exceeded 0.6 gram during the nose fairing jettison. The Lewis test value never exceeded 0.82 gram.

During the previous flight high acceleration peaks during nose fairing separation were measured by accelerometers located near the equipment shelf. CA270 located on the A/P Gyro Package indicated a maximum of 5 grams peak to peak at nose fairing jettisons. The only accelerometer used on the Lewis test was CA890 located on the Guidance Platform and it indicated peak to peak accelerations of 26 grams. A plot of these accelerations is shown on Figure 8-1. Strain gauges CA38S and CA39S indicated the vertical loads on the nose fairing flight hinges. Figure 8-2 shows the loads placed on these hinges during flight and during the Lewis test. The maximum compressive load of 2600 pounds was well under the load capacity of approximately 8000 pounds. The loads in Figure 8-2 were obtained by doubling the indicated load since only one leg of the two-leg hinge was strain gauged.

CM201D, CM202D, CM203D, and CM204D were position indicating transducers measuring the angular rotation of the nose fairing about its flight hinge. Figures 8-3 and 8-4 show the angular motion of the fairings, for the flight and for the Lewis test as obtained from these transducers and for the Lewis test as obtained from photographic data. The two methods of obtaining angular rotation during the flight qualification tests were in close agreement. The angular rate of rotation during flight as shown by these transducers was less than that obtained during the Lewis tests. Since transducers were located in each quadrant rotation about the Z-axis was observed. In the Q II-III fairing half, data from the flight showed that the Q III rate of rotation was more than the Q II rate whereas the Lewis tests showed the opposite to be true. The Q I-IV half did not show this discrepancy. In both cases the Q IV rate of rotation was higher than that of the Q I.

ATLAS/CENTAUR SEPARATION

The staging sequence had been exercised twice on previous Atlas/Centaur flights and its successful completion constituted a secondary flight objective. As in earlier flights, the separation process was initiated by the linear shaped charge which fired at T + 226.76 and severed the interstage adapter at Station 413.

The retro-rockets fired at approximately T + 226.9 to decelerate the Atlas and preliminary accelerometer data indicates all eight rockets ignited. The rocket fairing cap breakwire data was not readable to the extent it could be relied upon to verify rocket firing in all instances.

Information obtained from gyros indicated that the Centaur did not rotate about its center of gravity to an appreciable amount during the separation process (less than 0.2°). It is also indicated that the Atlas did not rotate significantly about its pitch axis which is the more critical axis. A rotational motion component about the yaw axis was noted which resulted in a yaw of approximately 0.7° at the time the Atlas cleared the Centaur. The resulting path of the forward edge of the interstage adapter from the angular Atlas motion is shown in the accompanying Figures 8-5 and 8-6.

The rotational and translational motion components are shown in Table 8-1 and compared with the predicted values. It will be noted that the critical pitch (Y-Y) motions are small (both predicted and observed). The yaw (X-X) motion, which is predicted to be wholly rotational, is apparently significantly greater than predicted. However, as shown in Figure 8-6, a clearance of approximately 33 inches still exists after 9 feet of longitutinal separation to absorb any undetected motion before a collision would occur.

TABLE 8-1

MAGNITUDES AND DIRECTIONS OF ATLAS COMPONENTS OF MOTION AT FORWARD EDGE OF INTERSTAGE ADAPTER AFTER 9 FEET OF LONGITUDINAL MOTION

Component	Predicted along X-X axis, in.	Observed, in.
Translation	0	--
Rotation	+2	+7
Total	+2(along Y-Y axis)	+7
Translation	$-1\frac{1}{4}$	--
Rotation	$-\frac{1}{4}$	-1
Total	$-1\frac{1}{2}$	--

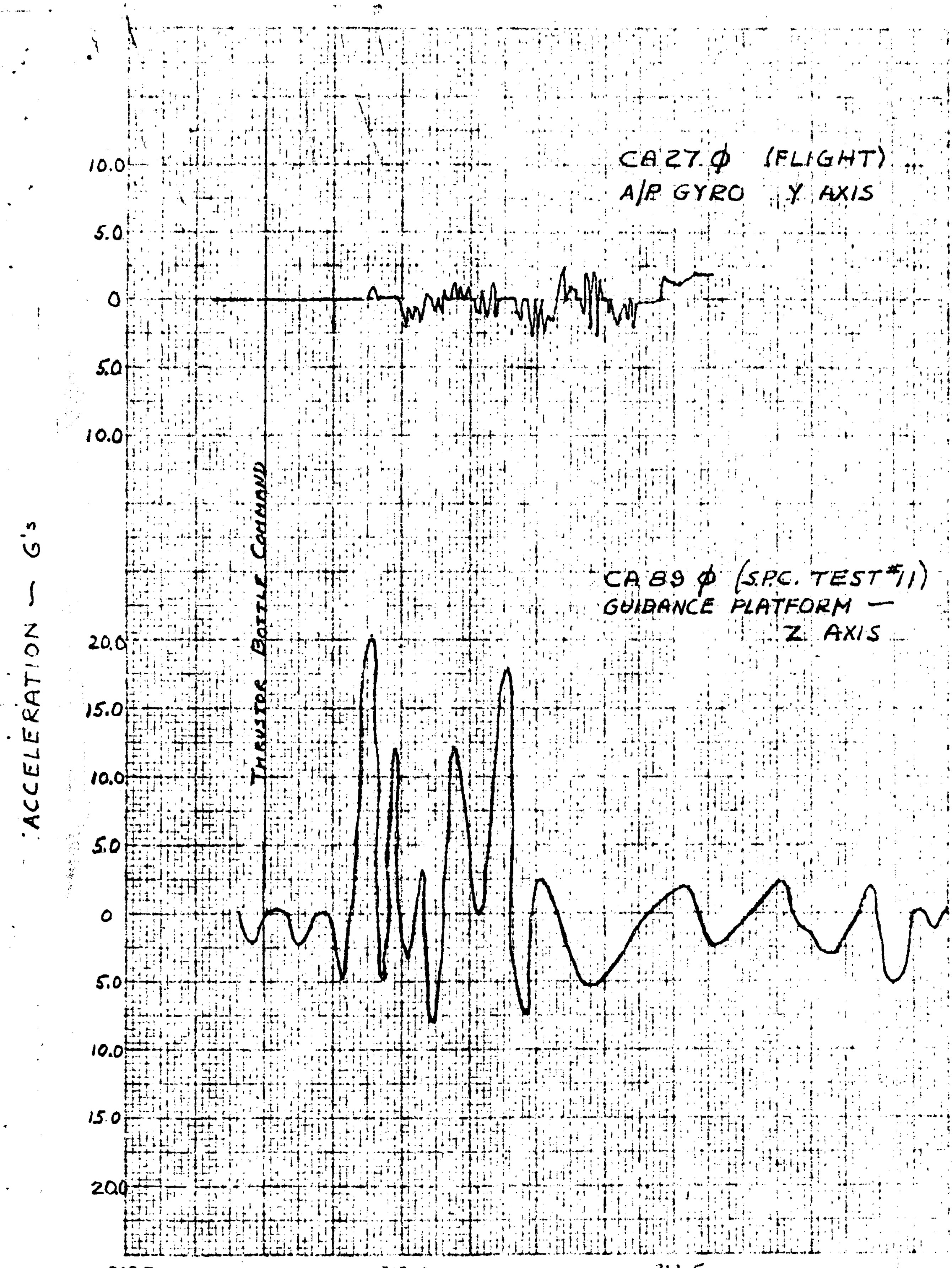


FIG. 8.1 — NOSE FAIRING SEPARATION
EQUIPMENT PLATFORM ACCELEROMETERS

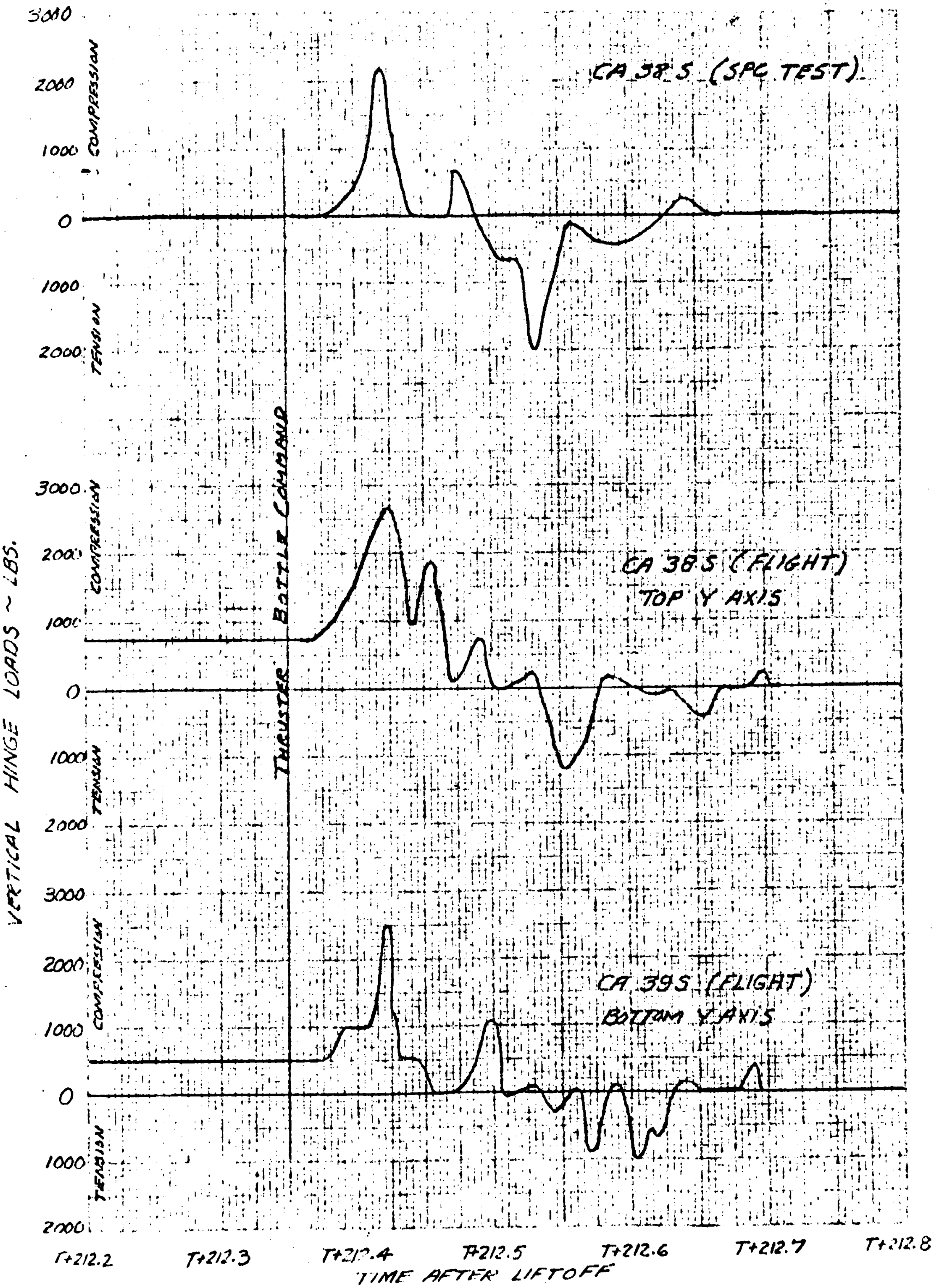


FIG. 8.2 NOSE FAIRING SEPARATION VERTICAL HINGE LOADS

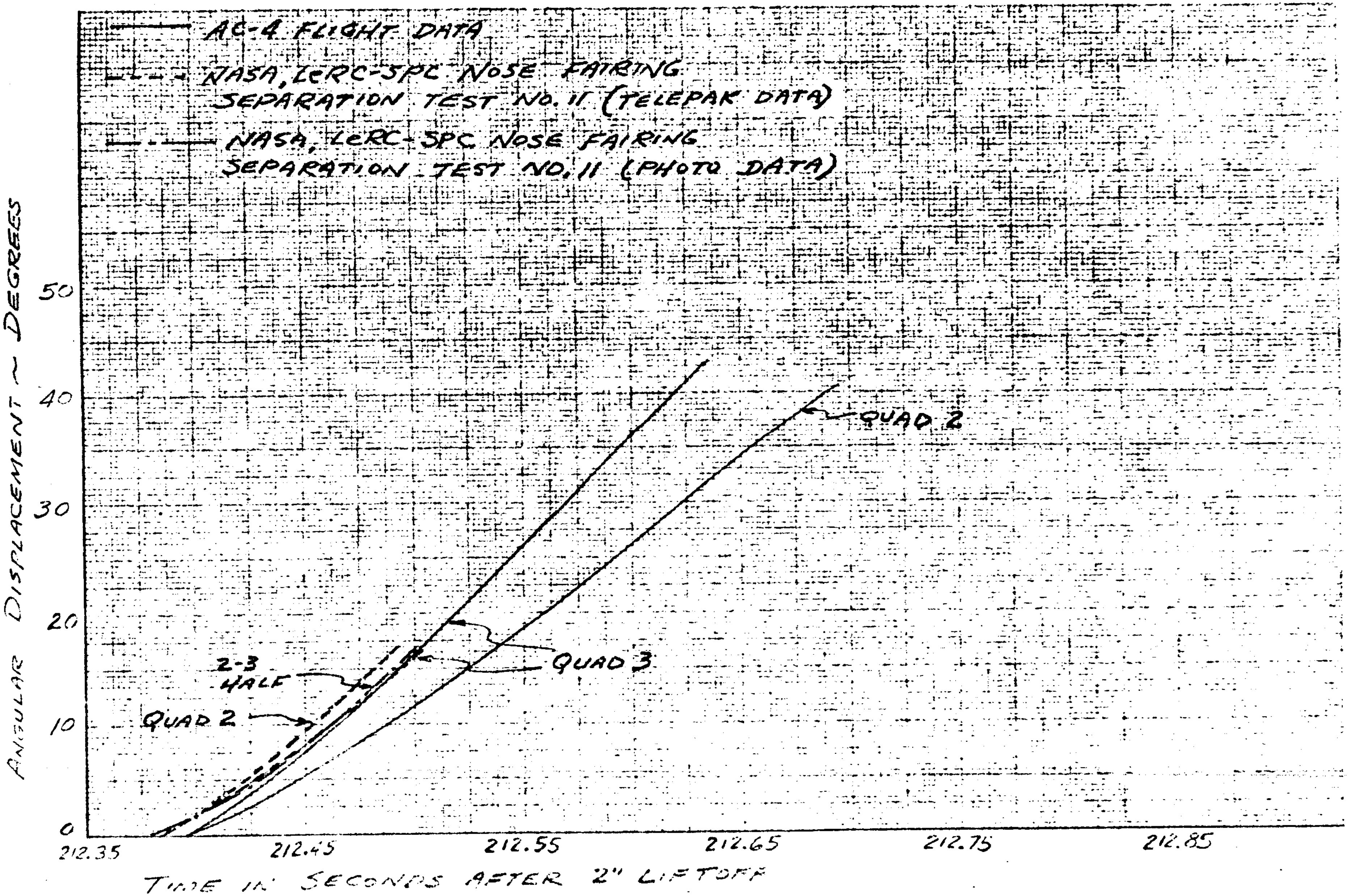


FIG. 8 3 NOSE FAIRING SEPARATION — ANGULAR MOTION OF FAIRING

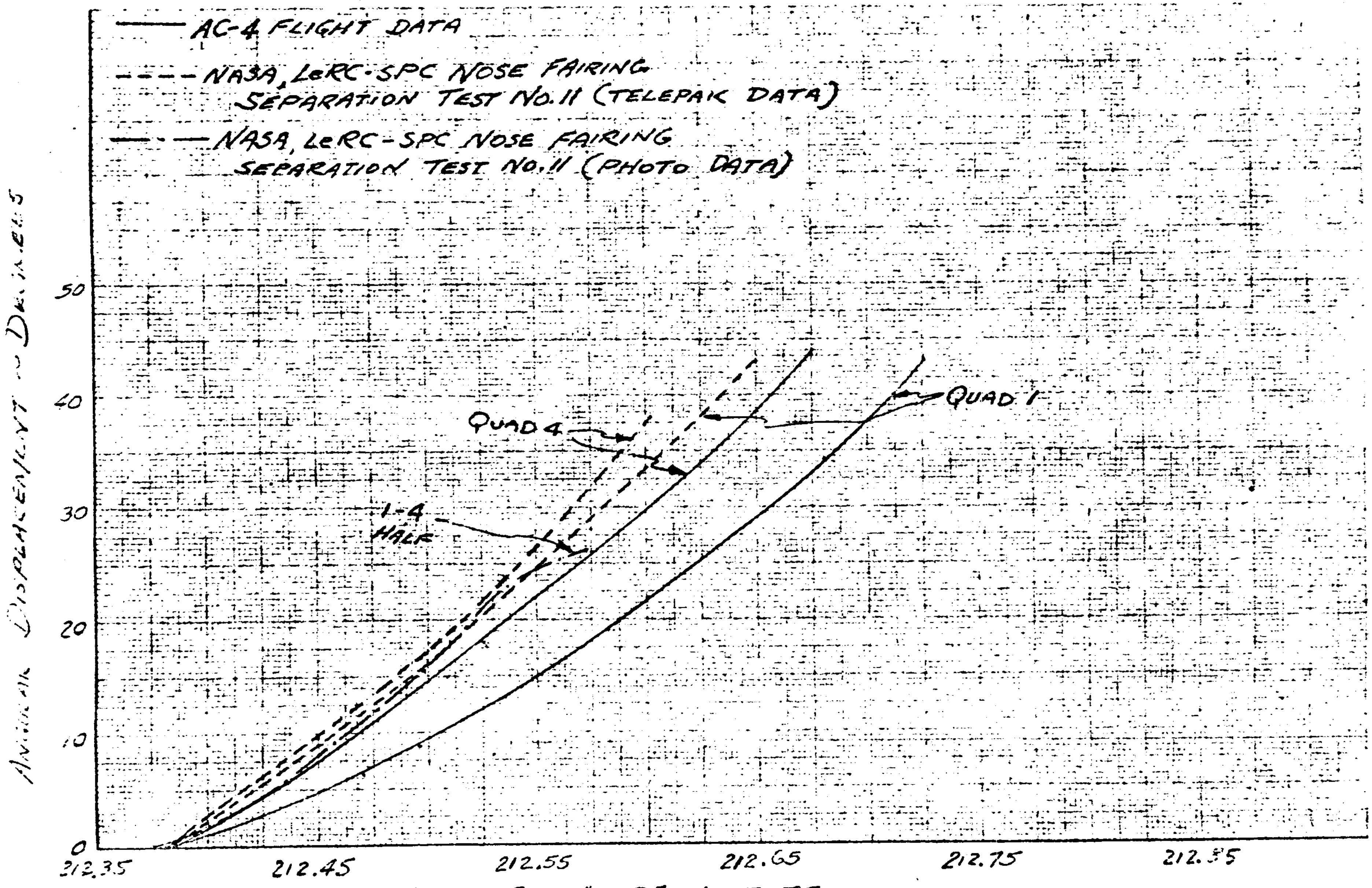
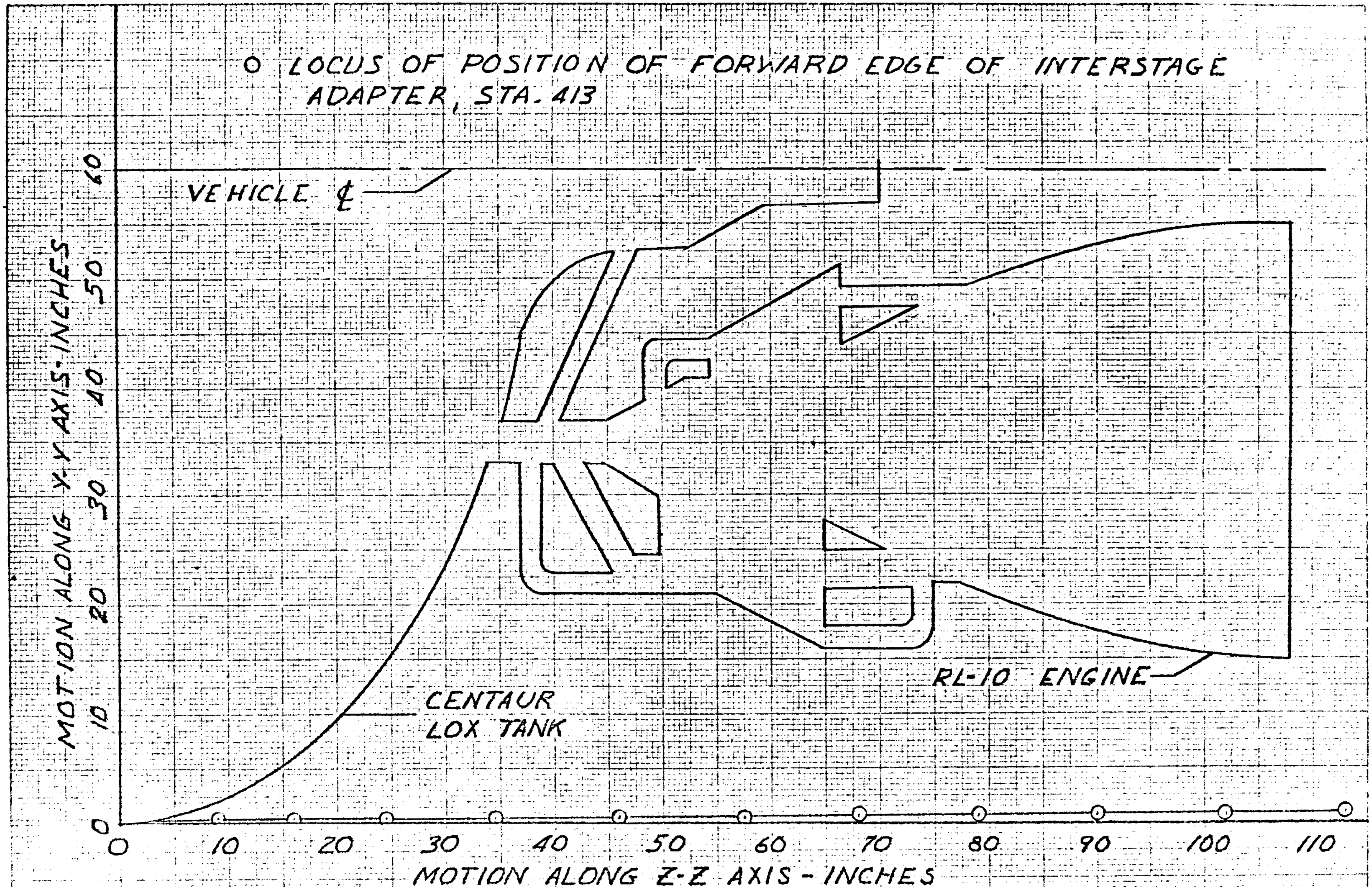
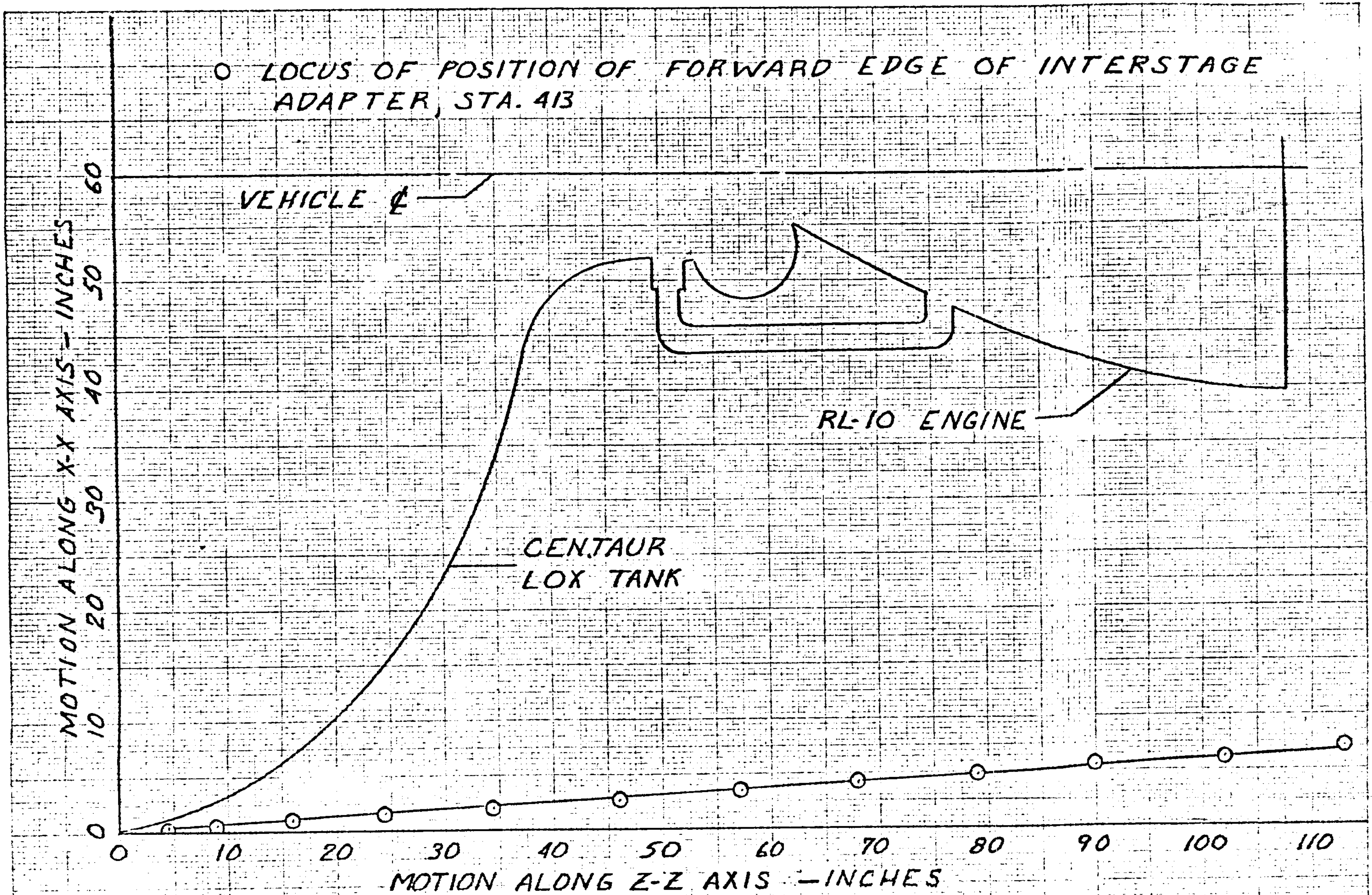


FIG. 8-4 NOSE FAIRING SEPARATION ~ ANGULAR MOTION OF FAIRING



MOTION IN Y-Z PLANE OF STA. 413 ON ATLAS WITH RESPECT TO CENTAUR DURING STAGING OF AC-4 FLIGHT

FIG. 8.5



MOTION IN X-Z PLANE OF STA. 413 ON ATLAS WITH RESPECT TO CENTAUR DURING STAGING OF AC-4 FLIGHT

FIG. 8.6

SECTION 9. VEHICLE STRUCTURES

SUMMARY

In achieving its initial parking orbit, the AC-4 vehicle demonstrated its ability to withstand all structural loads imposed during the powered phases of the flight. Structural integrity of the Centaur stage was maintained even during uncontrolled tumbling following the first MECO. All elements of the vehicle structures system performed as predicted.

INSTRUMENTATION

The structural instrumentation consisted of strain gages, pressure and temperature transducers, accelerometers, microphones, and nose cap angle of attack transducers. Three strain gage measurements (two at Sta. 402 and one at Sta. 225) were not functional prior to the launch and no data was retrieved from them. At least one strain gage on the Atlas stage at Sta. 582 was lost during the flight. These are the only significant instrumentation failures of importance to structures that occurred on this flight. Data of acceptable quality was received from the rest of the instrumentation. Loss of a few strain gages will not seriously impair in depth evaluation of the structural system.

RESULTS

Flight Bending Moments

Vehicle angle of attack measurements are a prime source of evaluating bending loads encountered during the high dynamic pressure flight regime. The history of pitch and yaw angles of attack is shown in Figure 9-1. In the pitch plane the highest value of angle of attack was 2.24° at T+71 seconds. Unlike the sharp peaks on AC-3 on this flight the angle of attack (alpha) maintained a value of approximately 2^{o} from T+58 to T+62 seconds, and from T+70 to T+79 seconds. In general, the pitch plane angle of attack (alpha) was positive resulting in positive values of vehicle bending moment. In the yaw plane a maximum value of angle of attack (β) was -1.68^{o} at $T+78^{o}$. Here again there were no sharp peaks and in general through the high dynamic pressure flight regime β was negative with an absolute value being considerably smaller than alpha. The absence of sharp peaks may have been due to the type of transducer employed. On the AC-3 flight the main source of data was the stinger angle of attack measurement. This has a much higher frequency response than the nose cap differential pressure measurements employed on AC-4.

The bending load resulting from aerodynamic forces are shown in Figures 9-2 to 9-4 at Stations 219, 408, and 812. The first two stations (i.e., Sta. 219 and 408) represent major structural joints on the Centaur vehicle and Station 812 represents the station of maximum bending moment. From these data it is apparent that maximum values of bending moment encountered on the AC-4 flight were approximately 60 percent of the limit allowables. Analysis of strain gage response data now in process will be used to further evaluate flight loads. These loads appear to be in general agreement with loads predicted on the basis of prelaunch wind soundings. The T-0 HR wind sounding indicated that winds aloft reached their maximum value of 35 knots at 45,000 feet. From the small value of maximum wind velocity it is apparent that aerodynamic load resulted mainly from the pitch over program employed on this flight, which was tuned to the preflight nominal wind as shown in Figure 3-1(b). As can be seen, deviations from the preflight nominal wind are greater than the absolute wind speed through the high g flight regime.

NOSE FAIRING HINGE LOADS

The nose fairing hinges support the two fairing sections at jettison as each section pivots away from the Centaur tank. Concern was evidenced prior to the flight that the nose fairing lugs would bottom out on the hinge aft fork and transfer nose fairing inertia and drag loads into the hinge. To alleviate this possibility, the fork opening was widened and care was taken to create a gap between the nose fairing lug and the aft fork of the hinge.

The flight data seems to indicate that this procedure achieved its aim. No compression (aft loads) were noticed until after T+180 seconds. Tension (forward loads) were noticed on the top Y-axis hinge during the transonic period. The flight loads were well within the limit load capacity of 6000 pounds. For actual jettison loads see SECTION 8. Tension loads prior to jettison indicated some transfer of bending moment into the hinges.

CENTAUR TANK STRUCTURAL INTEGRITY

Recorded pressures in the Centaur LOS and LH_2 tanks were normal throughout suborbital flight as was the differential pressure across the intermediate bulkhead. Detailed plots of the pressure versus time variation of the tanks may be seen in Figure 7-1. As may be seen in these plots, the pressures were well within the structural allowables.

NOSE FAIRING PRESSURE AND TEMPERATURE ENVIRONMENT

The nose fairing on the AC-4 flight was proven to be structurally reliable as temperatures and pressures were below predicted values, all discrete commands were initiated as programmed and all instrumentation to the nose fairing disconnected at the time of nose fairing jettison indicating normal jettison sequence.

The actual external temperatures during flight were lower at all stations than those predicted in the loads report; this was also true of pressures. Maximum crushing pressures encountered on the nose fairing occurred during transonic flight, transducers at Station 155 indicated peak crushing pressures of 0.3 psi in Quad I, 0.44 psi in Quad II, and 0.49 psi in Quad III. These values compare with a design crushing pressure of 1.8 psi. At Station 180 Quad IV a peak crushing pressure of 1.8 psi was recorded at T+58 seconds. However, the design value in this area is 3.3 psi. The umbilical island showed a crushing pressure of 3 psi at T+60 seconds, again well below the design value of 5.2 psi.

Temperatures on the nose cap reached maximum values at BECO. They were 576° F at the stagnation point (CA80T), 490° F, 30° from the Z-axis (CA958T), and 320° F, 60° from the Z-axis (CA959T). See Figure 9-5 for flight history of these measurements. None of these temperatures were near the critical fiberglass glue-line temperature, indicating the nose cap to be structurally sound for this flight. It appears that the only problem which could possibly have been present at these temperatures is gasification of the epoxy in the inner compartment which could contaminate the payload area. Measurements in the conical region indicate that a benefit of approximately 43° F was derived from application of Thermolag. Table below indicates relative effectiveness of the Thermolag:

Station, in.	Orientation, axis	Maximum temperature, °F	Thermolag
72	+Y	161	Covered
72	-Y	150	Covered
72	+Y	204	Not covered
72	-Y	193	Not covered

All discrete commands, that is, unlatch fairing command and fairing thrust bottle command were verified. All pressure and temperature instrumentation disconnected at the time of nose fairing jettison verifying a normal separation.

HYDROGEN VENT STACK TEMPERATURE

External temperature recorded on the leading edge of the hydrogen vent stack at a point 18 inches outboard of the nose fairing external skin reached a maximum of 975° F at T+150 seconds, as shown in Figure 9-6. Maximum predicted temperatures indicated a value of 1600° F at this location. The temperature measurement throughout the flight, prior to nose fairing jettisoning, were continuous and uninterrupted indicating all plies on the vent stack to have remained attached to the vent stack throughout the flight. It should be noted that at the time of maximum loading (Max. g) the recorded vent stack temperature was less than 100° F indicating a negligible loss in strength properties.

THRUSTOR BOTTLE COMPARTMENT PRESSURE

The thruster bottle compartment pressure dropped from approximately 14.7 psi to flight vacuum at nose fairing jettison. At this point there is a pressure peak of about 9 psi due to thruster bottle pressure. This pressure peak is higher than the pressures of approximately 5 psi measured during SPC tests of the nose fairing but is not considered detrimental to any structure in this area. Further detailed examination of the data in this area is in progress.

PAYLOAD ADAPTER AND SPACECRAFT TEMPERATURES

All temperatures on the mass model, separation latch points and payload adapter were within predicted values during the AC-4 flight. Temperatures ranged from 70° F at the top of the payload mast to -130° F at the payload adapter to tank attachment (Sta. 171).

PAYLOAD ADAPTER LOADS AND STRESSES

The three strain gages mounted on the payload adapter longerons (directly below the separation latch points) indicate compression in the adapter increasing in intensity from launch to BECO. At BECO there is an abrupt decrease in payload adapter strains. Stress levels do not exceed 10,600 psi in the adapter longerons, indicating that good structure margins of safety exist in this area.

INSULATION PANEL PRESSURE AND TEMPERATURE ENVIRONMENT

Locations of the various pressure measurements on the insulation panels are shown in Figure 9-7. External pressure decay history is shown in Figure 9-8. Its value reaches zero at approximately T+120 seconds.

Insulation panel differential pressure history during the flight shows that a crushing pressure exists throughout most of the flight. Only in a few cases do the pressure curves become negative which indicates a bursting pressure acting on the panels. The maximum crushing pressure recorded was 3.04 psi and the maximum bursting pressure recorded was 0.38 psi. The maximum crushing pressure occurred at T+70 seconds. This is immediately after the Mach 1 shock wave passed down the panels. The movement of this shock wave is the cause of the pressure increase at this time. The differential pressure history is shown in Figures 9-9 and 9-10. All the differential pressures are well within design limits for the insulation panels and lower than the predicted values.

Locations and designations of the insulation panels temperature transducers are shown in Figure 9-11. At the time of lift-off, five of the thermocouples read temperatures between -340° and -370° F. The predicted temperature at lift-off was -360° F. This corresponds very well with actual temperatures. One thermocouple (CA381T) did not fall within the above temperature range, reading -260° F at lift-off. A reasonable explanation for this is the fact that the thermocouple is near the helium purge ring and the warm helium is impinging upon it while the vehicle is on the ground. After lift-off the temperature readings gradually increase with time. At panel jettison the temperature range is -290° to -330° F. This behavior is as expected, because of the heat flux into the panels. CA381T, however, behaves in the opposite manner. It cools as the time increases until it reaches -299° F at panel jettison. Time histories of internal insulation panel temperatures are shown in Figures 9-12 and 9-13.

An explanation for this phenomenon could be the fact that upon lift-off an airborne helium purge is being used. This purge had a much lower flow rate and uses cold helium gas which would allow the thermocouple reading to decrease. The existence of a Thermolag coating on the outside skin of the panels will also prevent the temperature from rising.

Thermocouples CA595T, CA597T, CA599T, CA701T, CA705T, and CA7057 were used to obtain the temperatures on the outside of the insulation panels. Time histories of insulation panel external temperature measurements are shown in Figures 9-14 to 9-19. These thermocouples were mounted in the same position as the inside ones. They were mounted in the basic panel region and on or in close proximity to any panel protuberences. The maximum temperature recorded by five of the thermocouples ranges from +140° to +175° F. These temperatures are much lower than predicted. The highest predicted temperature in the basic panel region (cylindrical section) was +420° F and the highest actual temperature was +175° F read by CA701T which was located at Station 280. The sixth thermocouple read a maximum temperature of only +98.5° F. This thermocouple was located on the wiring tunnel panel at Station 395 in an area that was coated with Thermolag. The Thermolag increased the mass of the panel, thus the panel was able to absorb more heat without an increase in temperature. These temperatures cause only a small decrease in insulation panel material allowables.

Thermocouples CA20T and CA21T recorded the temperature on the outside skin of the wiring tunnel at Station 310 and 353. These thermocouples were located in the center of the wiring tunnel. The maximum temperature of 214° F was recorded by CA21T at T+150 seconds. This temperature is much lower than predicted temperatures and causes only a small decrease in insulation panel material allowables.

Thermocouples CA22T, CA23T, and CA24T give the temperatures in the area of the boost pump fairing. CA23T and CA24T are located on the outside of the boost pump fairing.

The temperatures recorded in this area are the highest on the insulation panels. The highest temperature is +234° F. This temperature, even though it was the maximum temperature recorded, is still well below predicted and design temperatures. CA22T was located in a basic panel region and is on a Thermolagged area, thus the temperature does not exceed a maximum of 80° F.

Thermocouples CA40T and CA41T read the outside temperatures in the area of the destruct package. These thermocuples were located in a Thermolagged area, thus the temperatures realized were much lower than predicted. The highest temperature read by either of these thermocouples was +88° F which is well within design limits.

Flight temperature data indicates that the aerodynamic heating analysis is very conservative and that a benifit of approximately 100° F was derived by application of Thermolag.

INSULATION PANEL SHAPED CHARGE DETONATION

TRANSFER BLOCK TEMPERATURES

There were four thermocouples, one on each of the detonation transfer blocks on the insulation panel shaped charge system. The detonation transfer blocks are located at Station 408. The temperature history recorded by these transducers is shown in Figure 9-20. The peak value attained was -4° F, and the minimum value recorded was 78° F. These temperatures are well above the redline limit of -250° F. These data indicate that there is no problem in this area.

ATLAS INTERMEDIATE BULKHEAD DIFFERENTIAL PRESSURE

The launch transient minimum differential pressure was 10.2 psi. Had the ullage pressures been at their most adverse (LOX 31, RP-1 57), the pressure across the bulkhead would have been 6.2 psi. The incremental load factor acting on the LOX due to launch transient is 0.23 g's, which is considerably less than the 0.6 g's assumed in the analysis.

The minimum differential pressure was measured at 99 seconds and was only 9.0 psi. Had the ullage pressures been at their most adverse (LOX 31, RP-1 57), the pressure across the bulkhead would have been 6.75 psi. There is a definite dip in differential pressure between T = 70 and T = 100 which did not occur during the flight of AC-3. Although the relative ullage pressures did change adversely (1.5 psi), this was not enough to reduce the differential across the bulkhead below a value of 10.7 psi.

ATLAS LOX TANK TEMPERATURES

The maximum predicted temperature at Station 575 was 640° F at T+172 seconds. At this time, the flight temperature was 230° F. The maximum measured temperature was 367° F, at 131 seconds. The predicted temperature for 131 seconds was 550° F. The actual point began heating, heated at lower rate, peaked earlier, and peaked lower than predicted.

The predicted maximum temperature at Station 580 was 455° F while the maximum measured temperature was 320° F. The predicted temperature at BECO was 380° F, while the measured temperature at BECO was 288° F.

The predicted maximum temperature at Station 574 was 450° F while the maximum measured temperature was 292° F. The predicted temperature at BECO was 380° F while the measured temperature at BECO was 280° F.

The measured values indicate a much less severe environment than does the analysis. The slightly lofted boost phase may account for some margin, but the analysis is still very conservative.

INTERSTAGE ADAPTER

The interstage adapter performed quite well throughout the complete flight. The maximum temperatures that were recorded during flight were well below the predicted temperatures for these data (see Figs. 9-22 to 9-24). The pressure and flutter data has not been reduced to a useable form yet, but from past performance, this data is expected to be well within the acceptable limits.

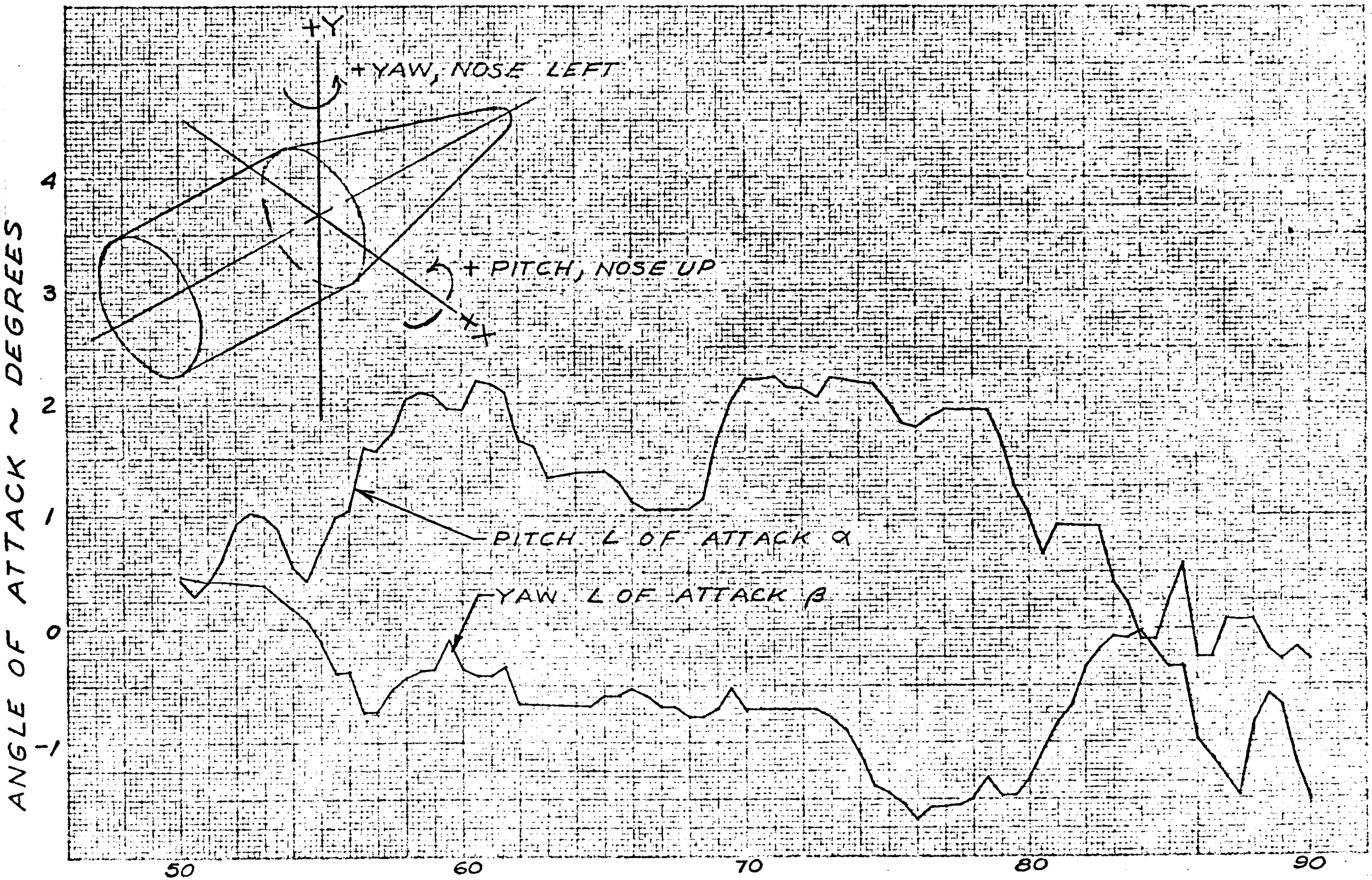


FIGURE 9-1. PITCH AND YAW PLANE ANGLE OF ATTACK (α & β) HISTORY DURING HIGH q ATMOSPHERIC FLIGHT REGIME (AC-4)

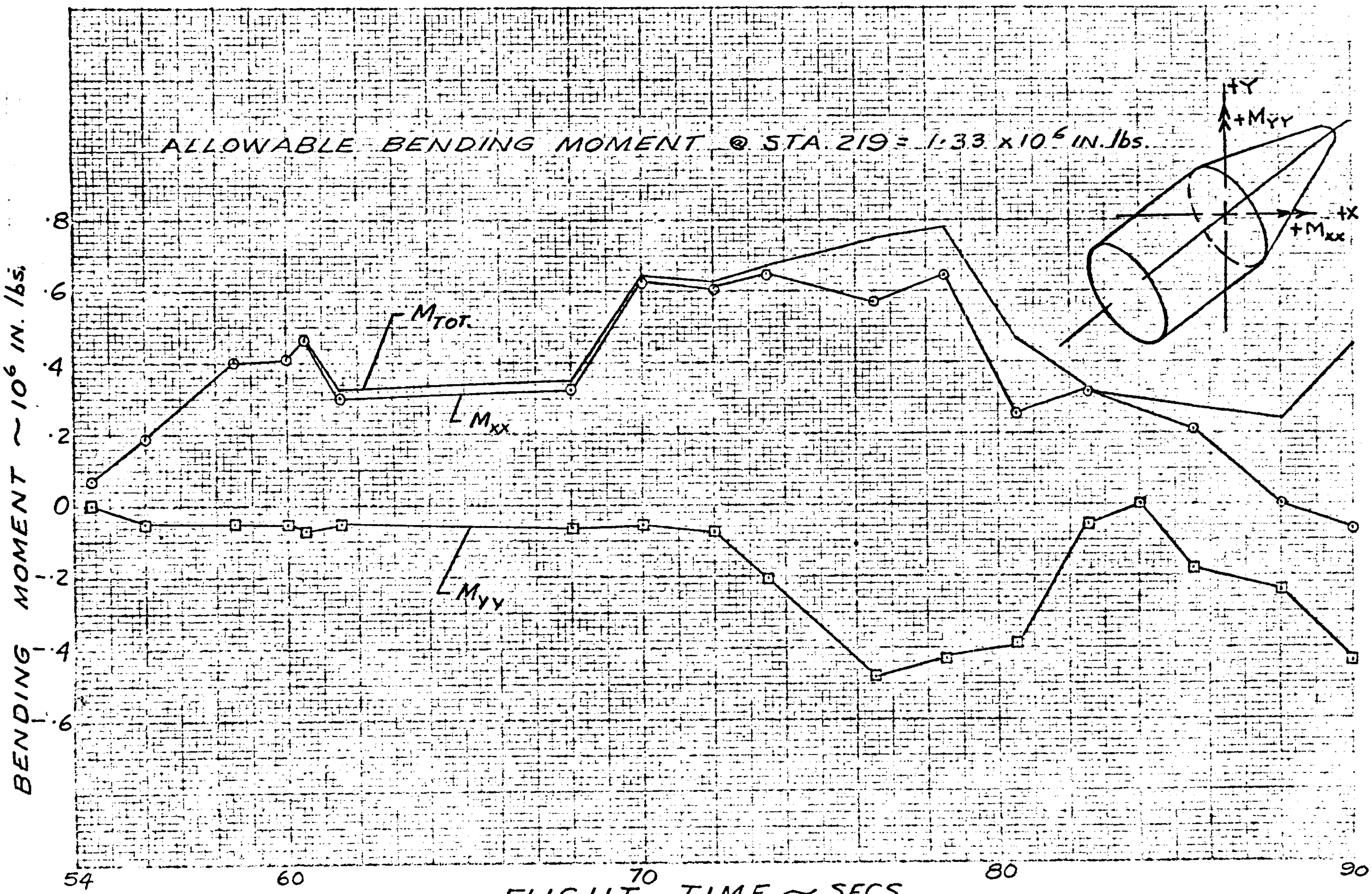


FIGURE 9-2. AC-4 BENDING MOMENT HISTORY AT STATION 219

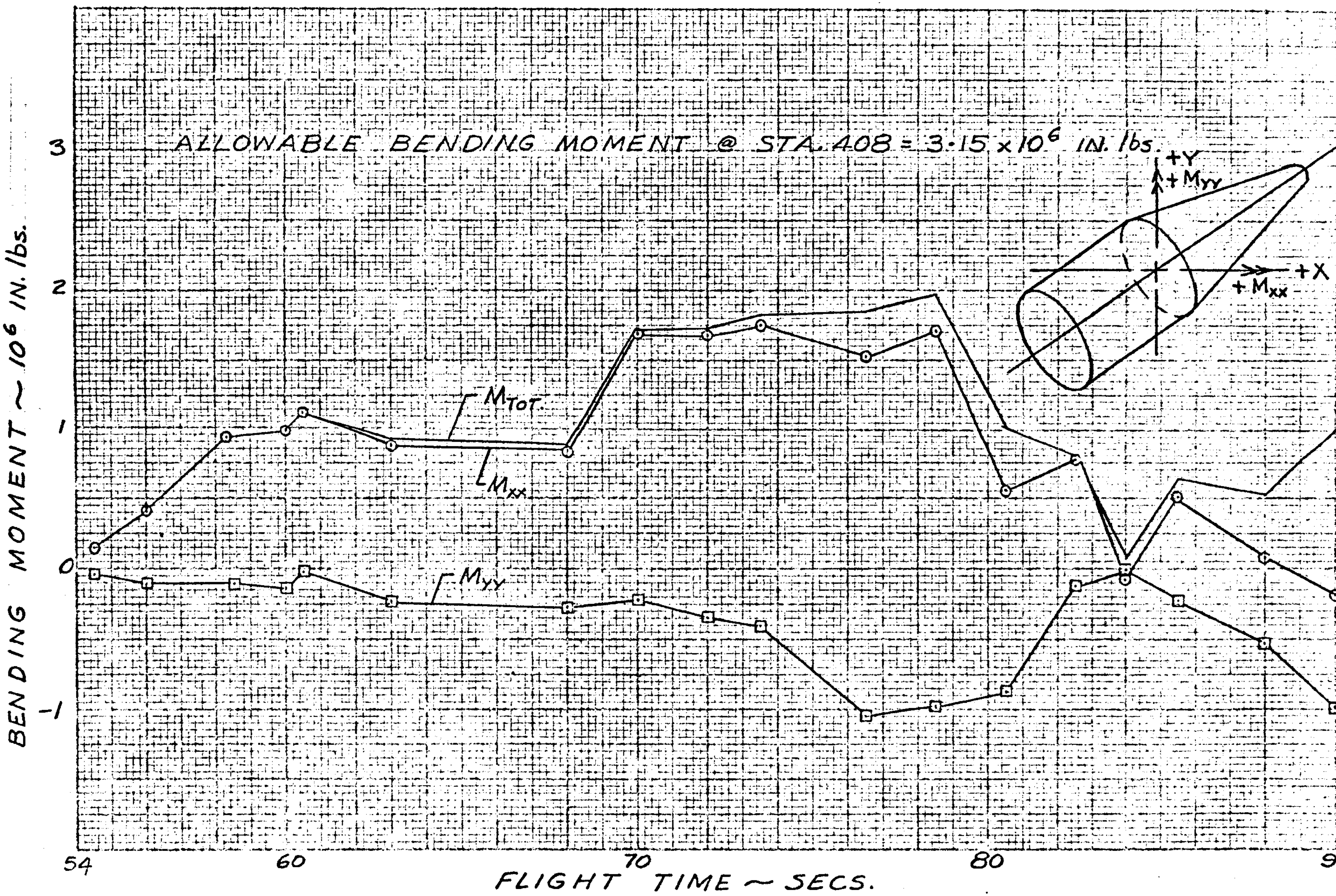


FIGURE 9-3. AC-4 FLIGHT BENDING MOMENT HISTORY AT STA. 408

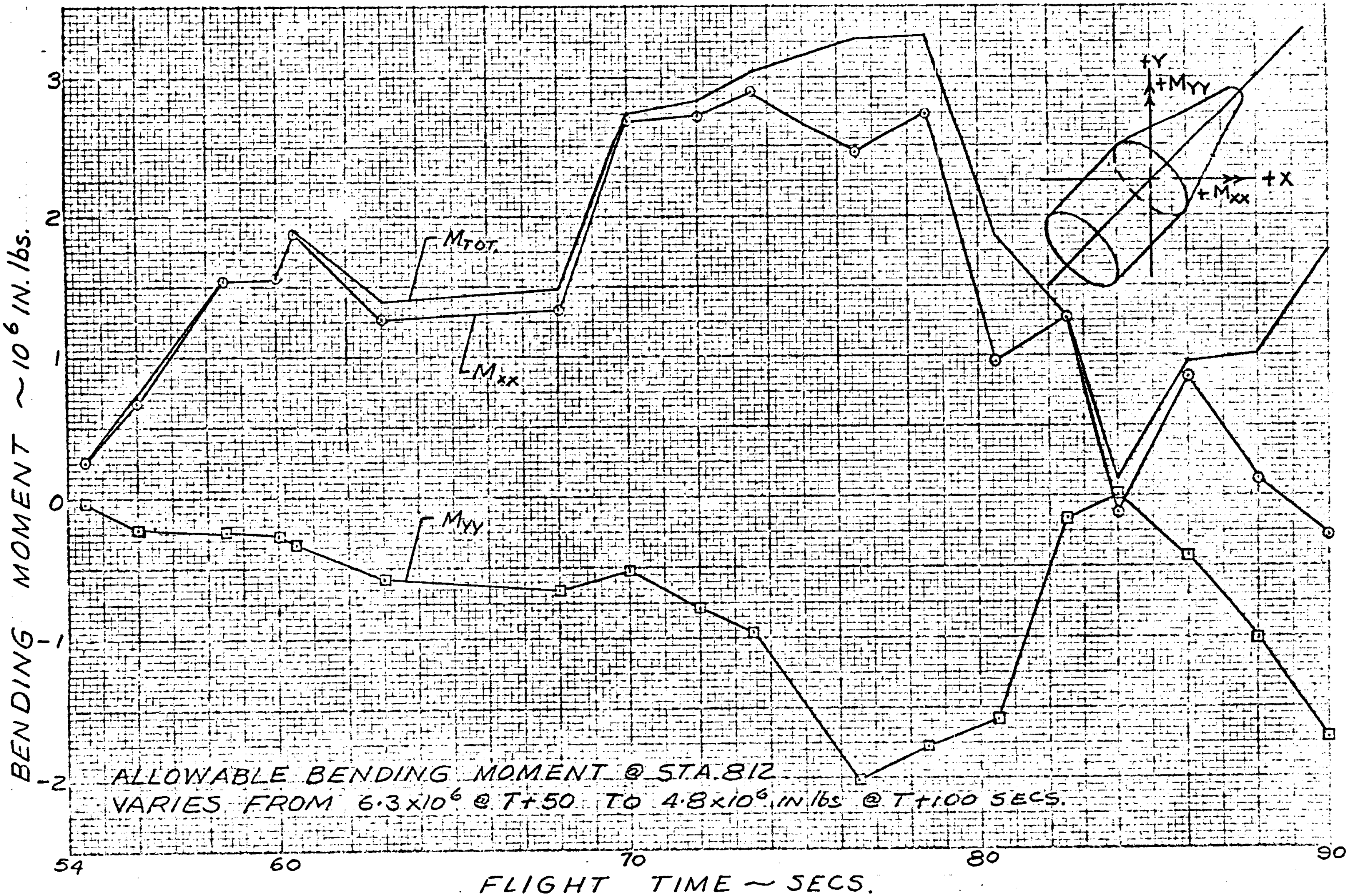


FIGURE 9-4. AC-4 FLIGHT BENDING MOMENT HISTORY AT STA. 812

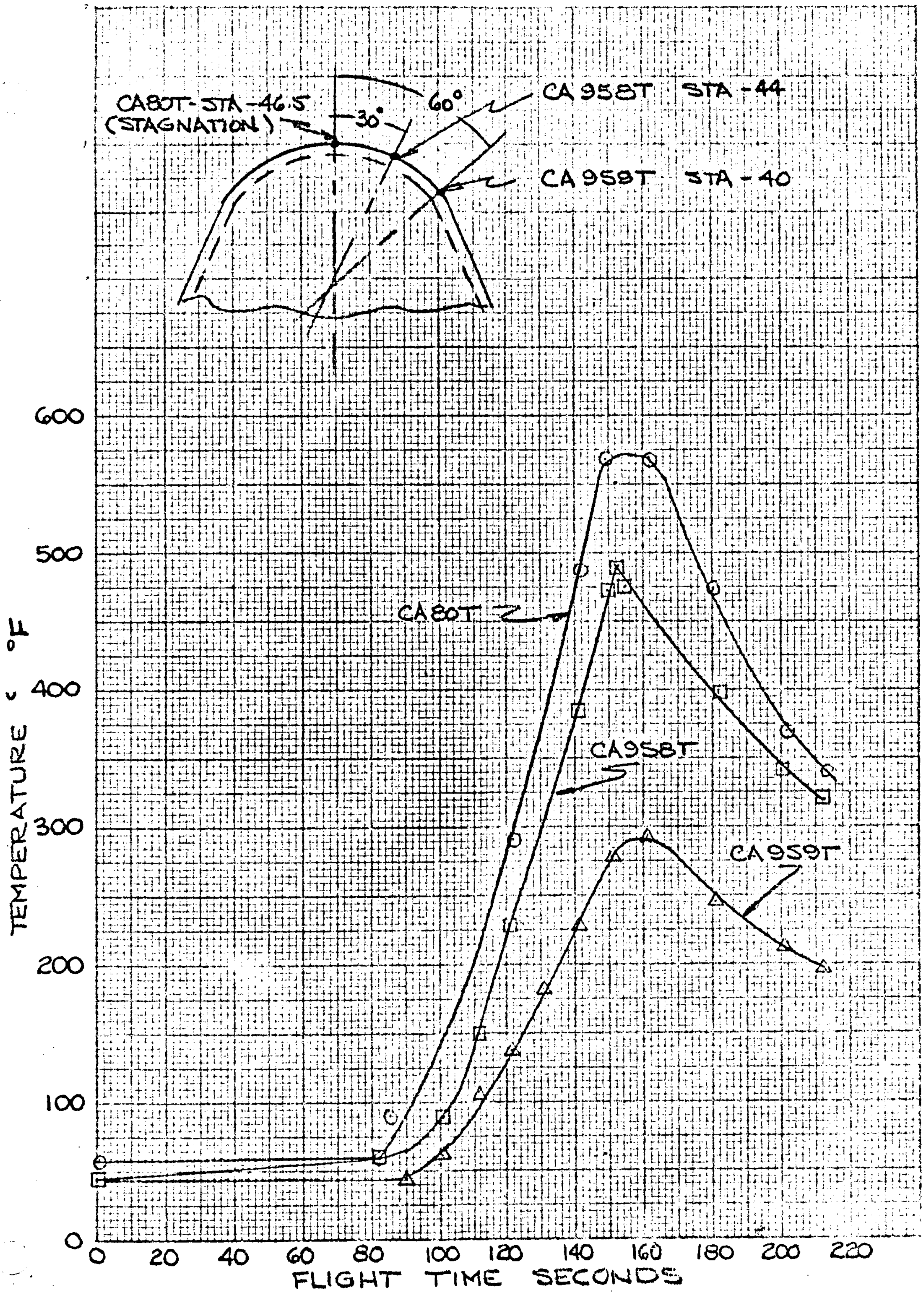


FIG. NO 9-5 NOSE FAIRING CAP TEMPERATURES

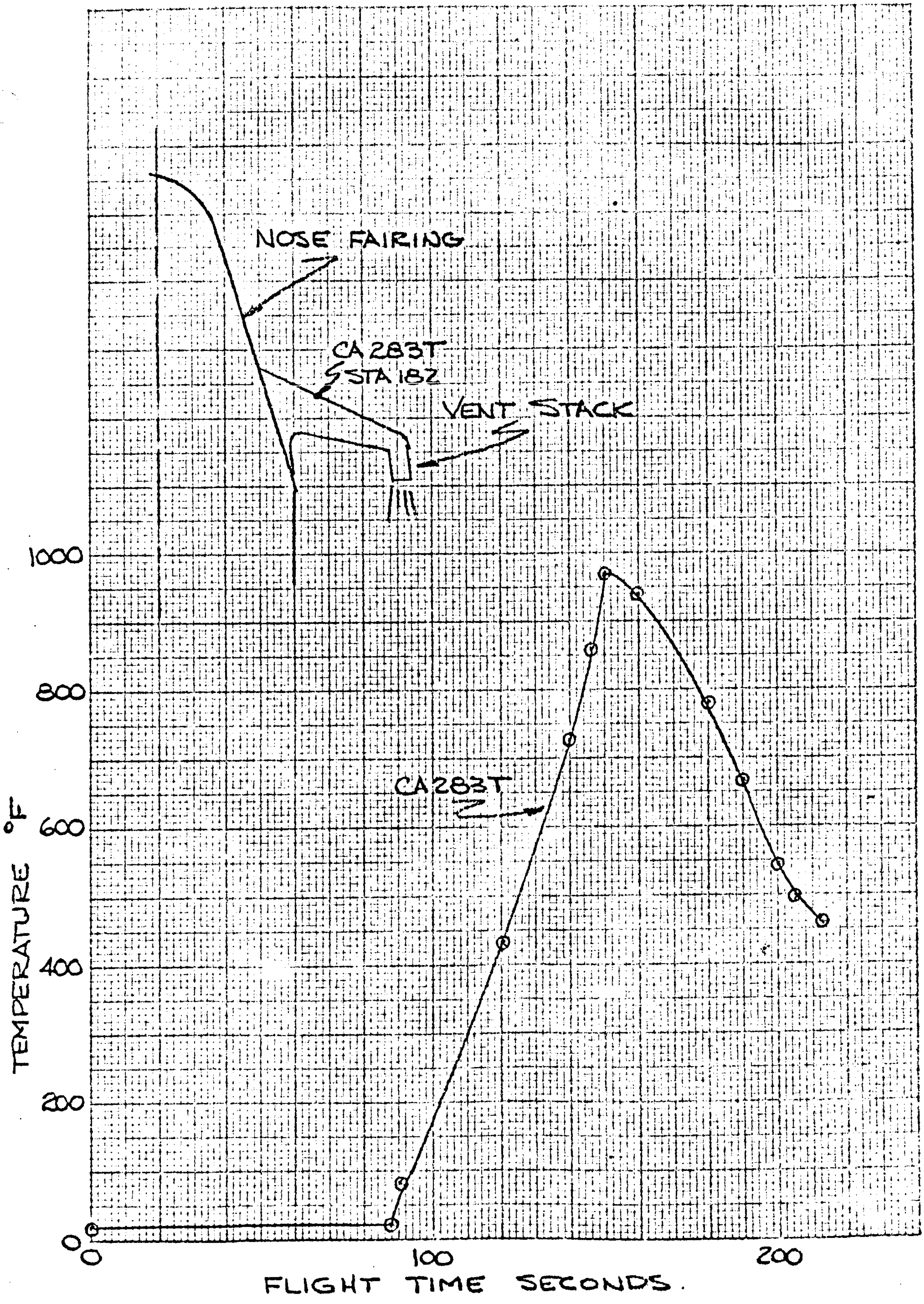


FIG. NO. 9-6 HYDROGEN VENT STACK TEMPERATURES

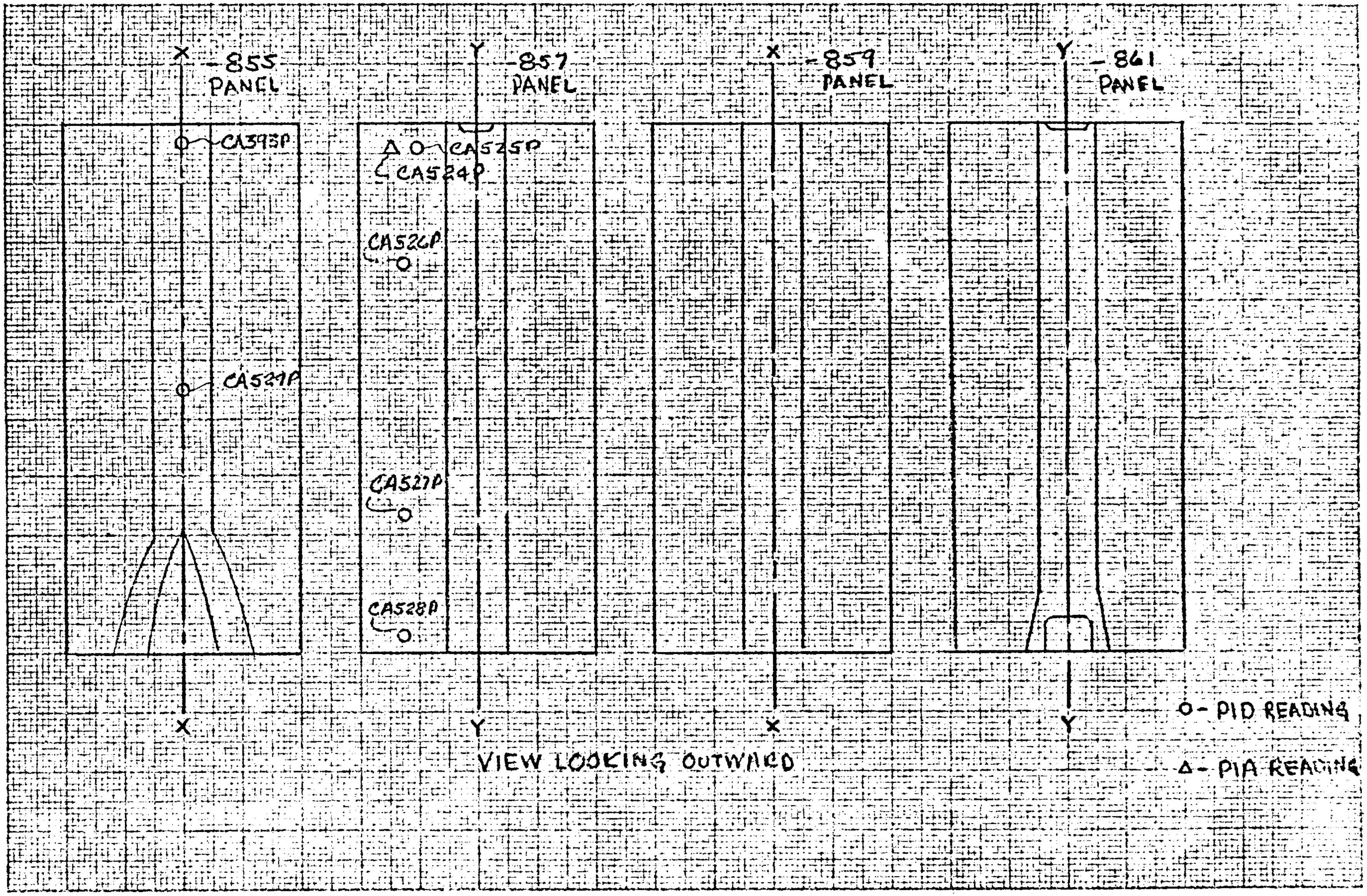


FIGURE 9-7 LOCATION OF INSULATION PANEL PRESSURE TRANSDUCERS

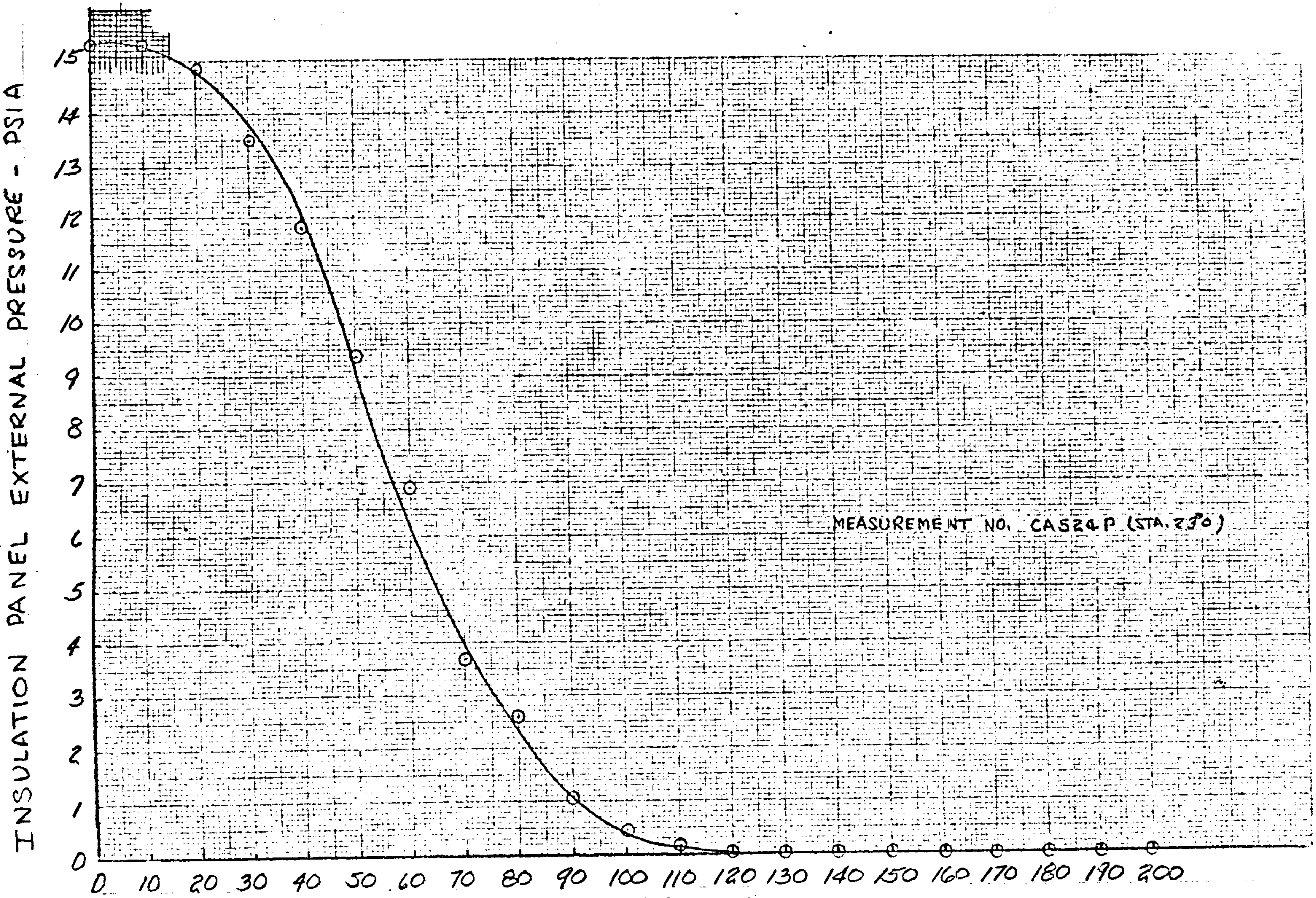


FIGURE 9-8
INSULATION PANEL EXTERNAL PRESSURE VS. FLIGHT TIME FOR CENTAUR AC-4

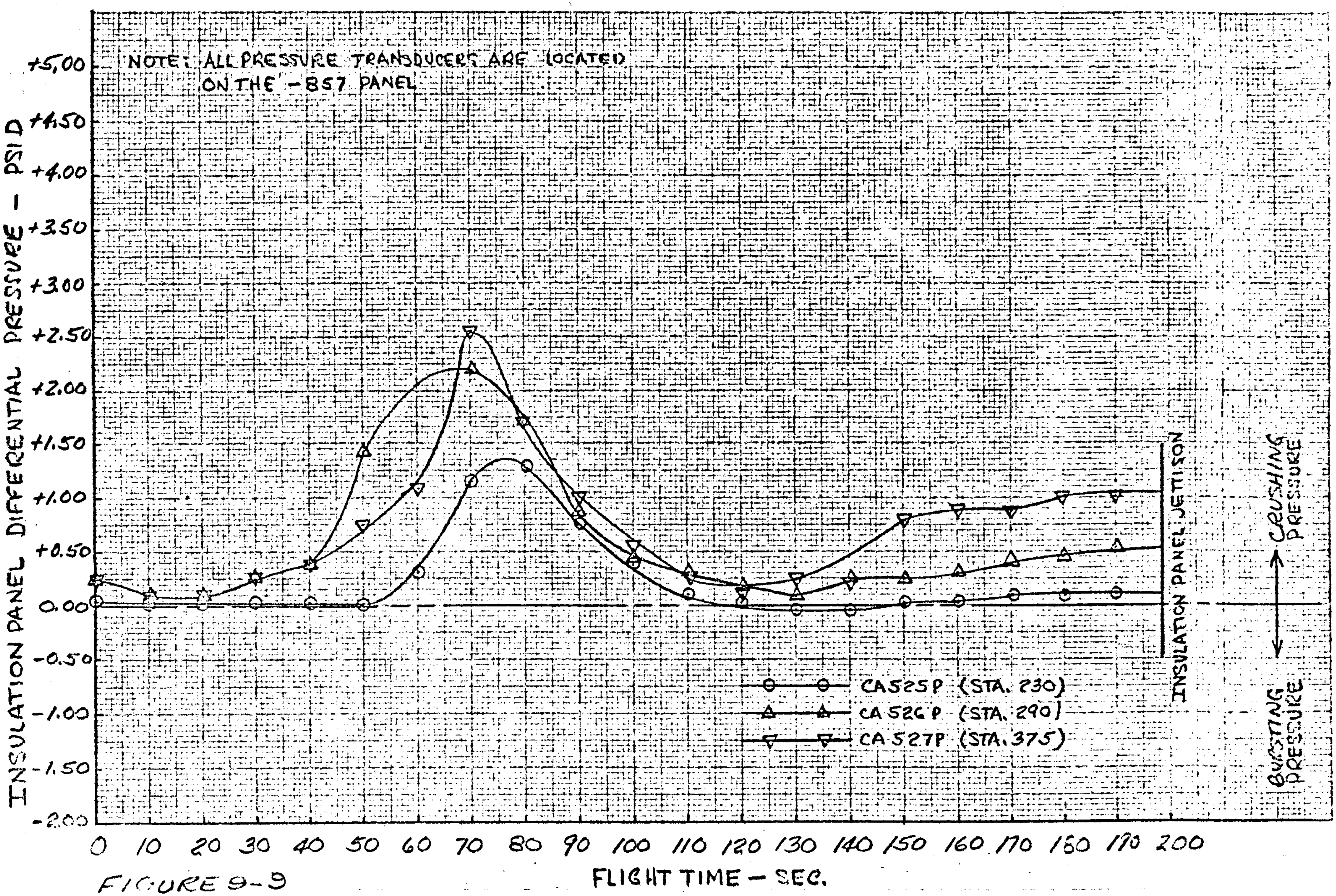


FIGURE 9-9

INSULATION PANEL DIFFERENTIAL PRESSURE VS. FLIGHT TIME FOR CENTAUR AC-4

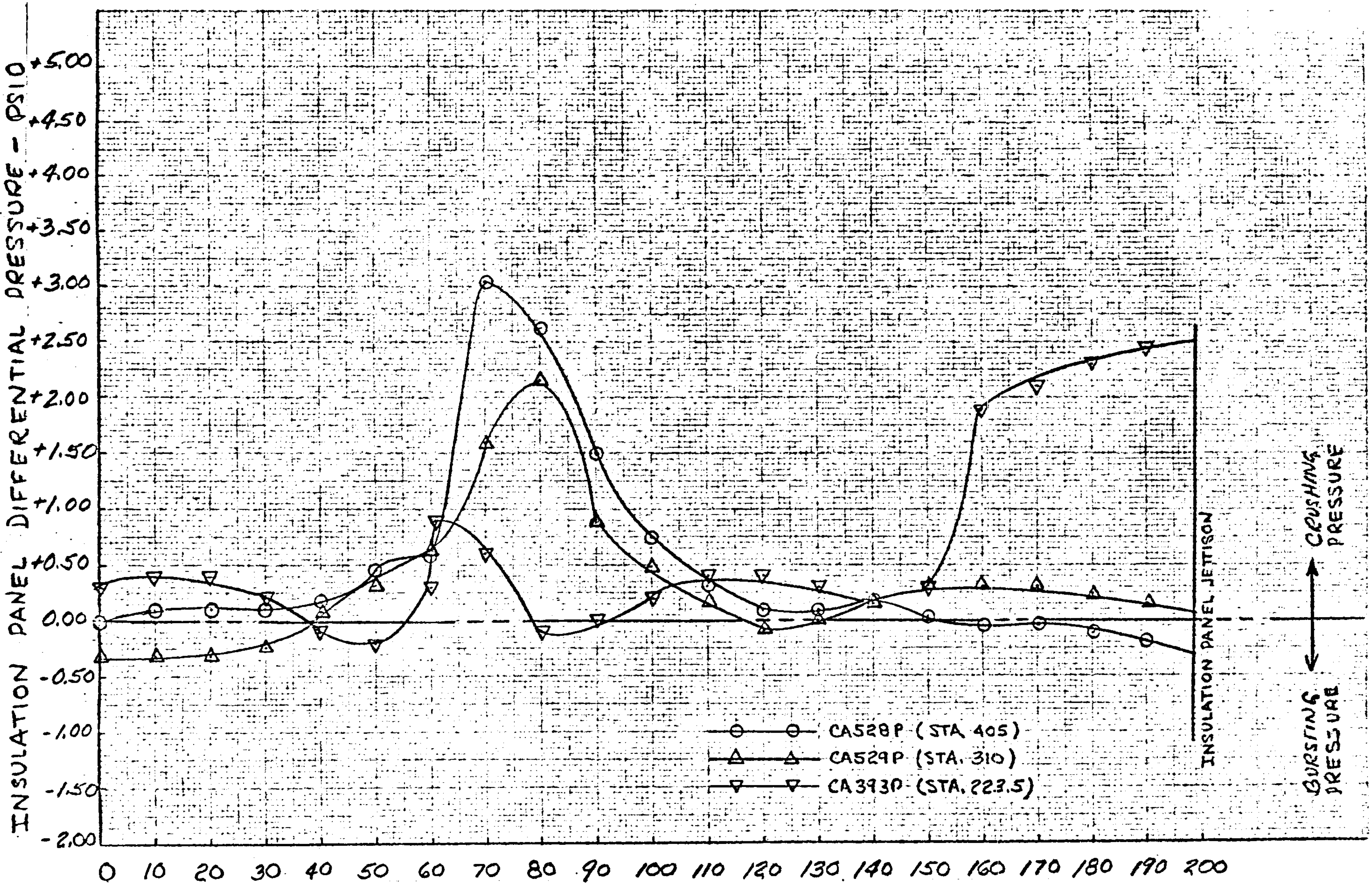


FIGURE 9-10

INSULATION PANEL DIFFERENTIAL PRESSURE VS. FLIGHT TIME FOR CENTAUR AC-4

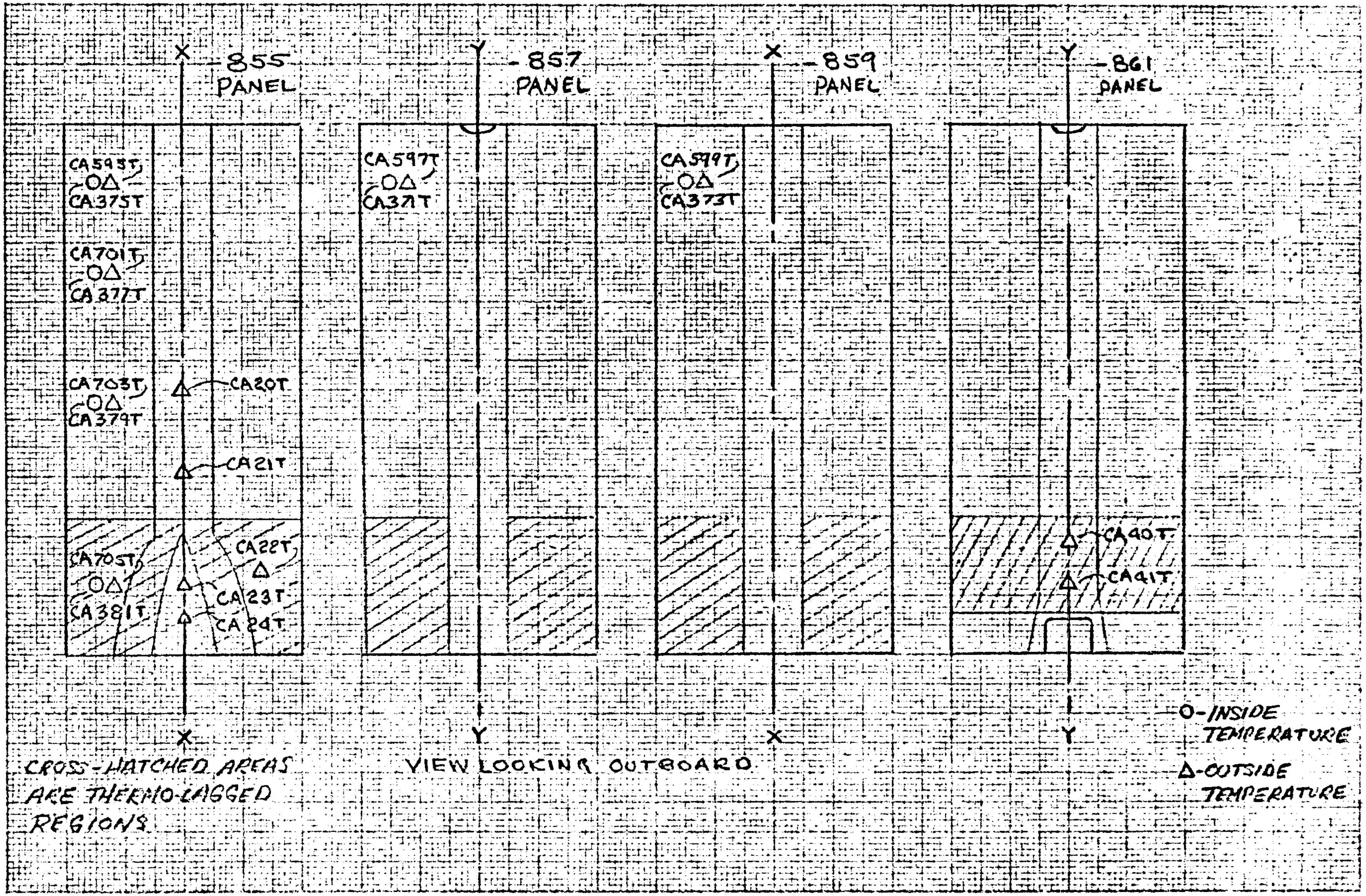


FIGURE 9-11 LOCATION OF INSULATION PANEL THERMOCOUPLES

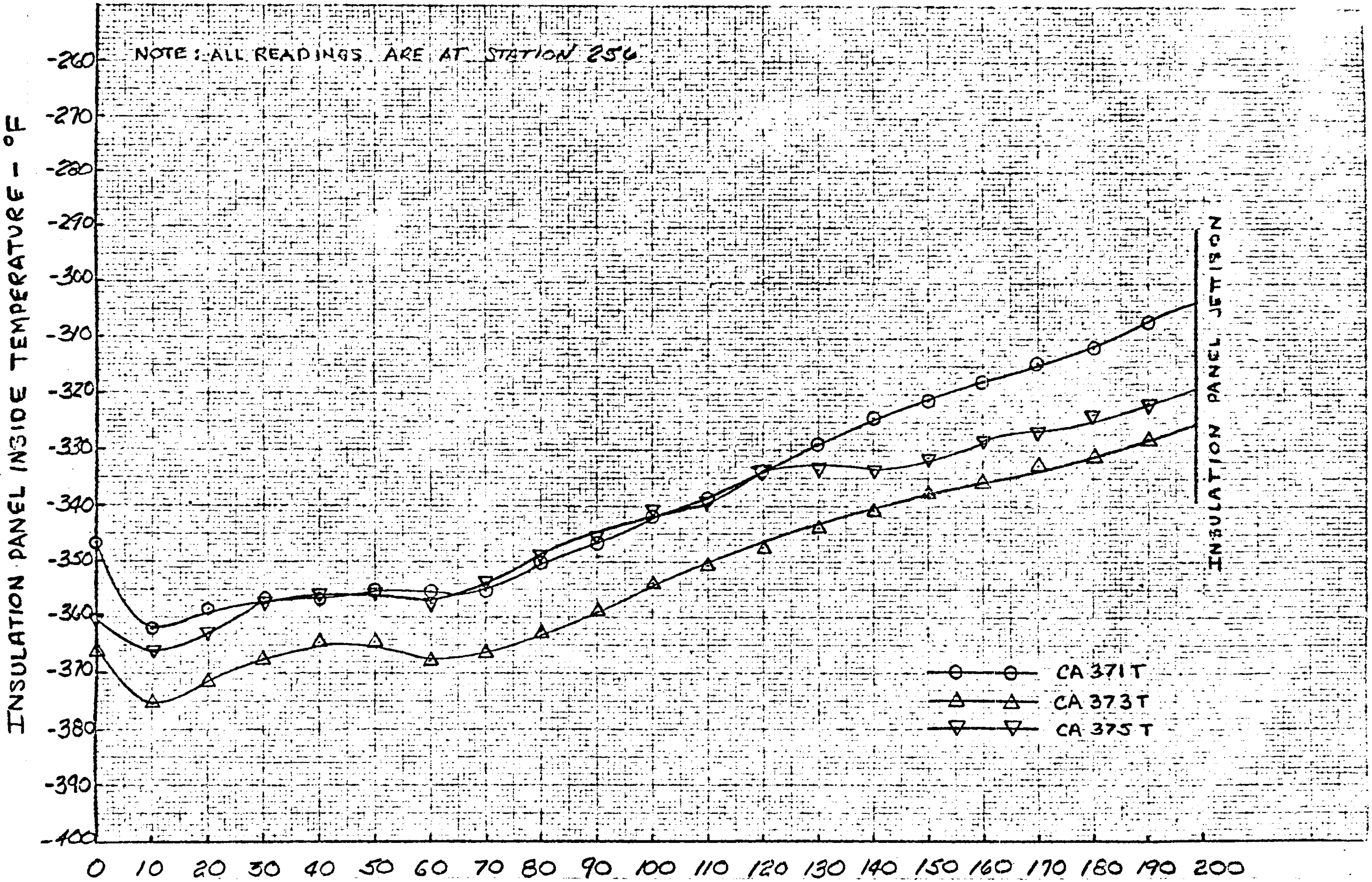


FIGURE 9-12
INSULATION PANEL INSIDE TEMPERATURE VS. FLIGHT TIME FOR CENTAUR AC-4

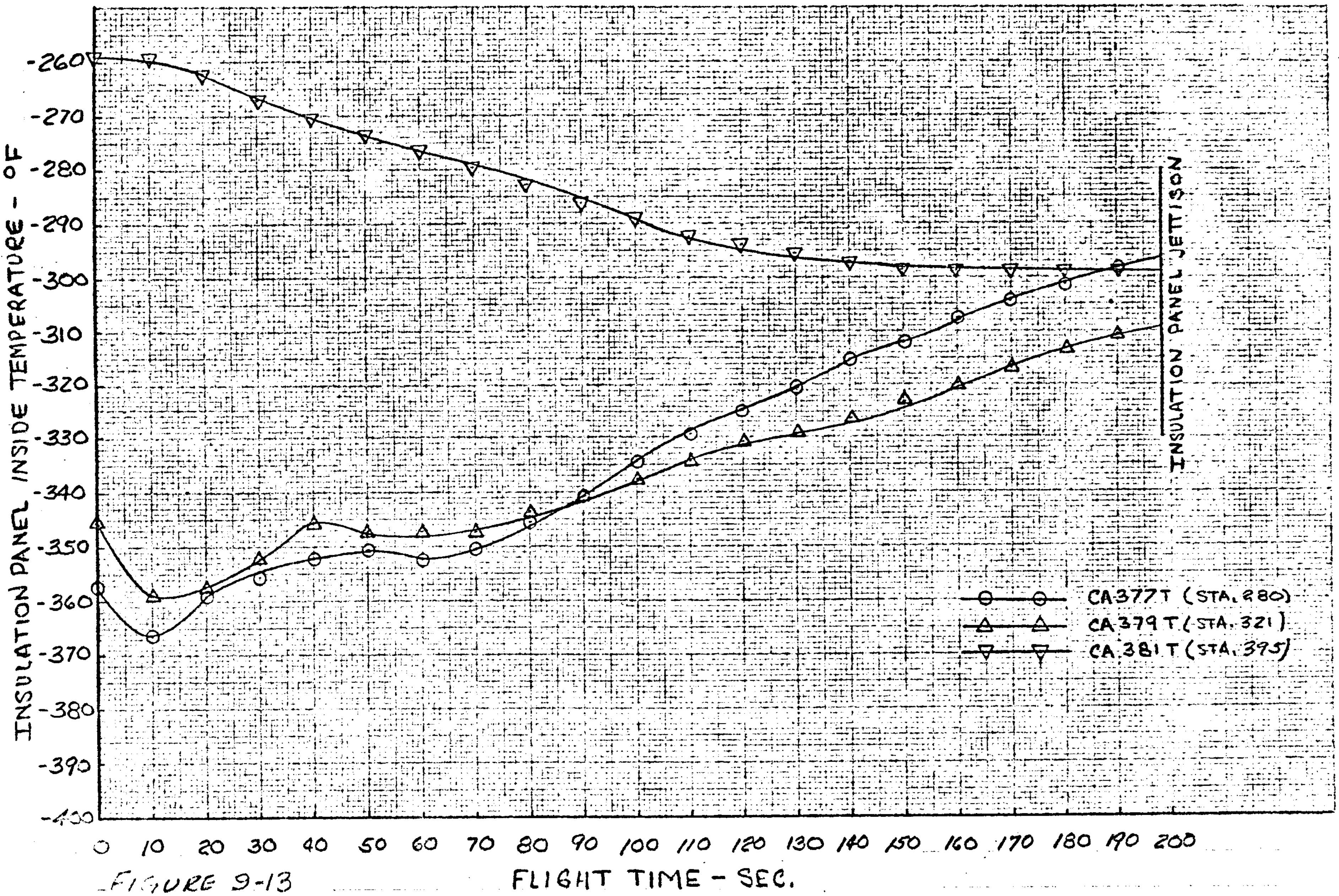


FIGURE 9-13
INSULATION PANEL INSIDE TEMPERATURE VS. FLIGHT TIME FOR CENTAUR AC-4

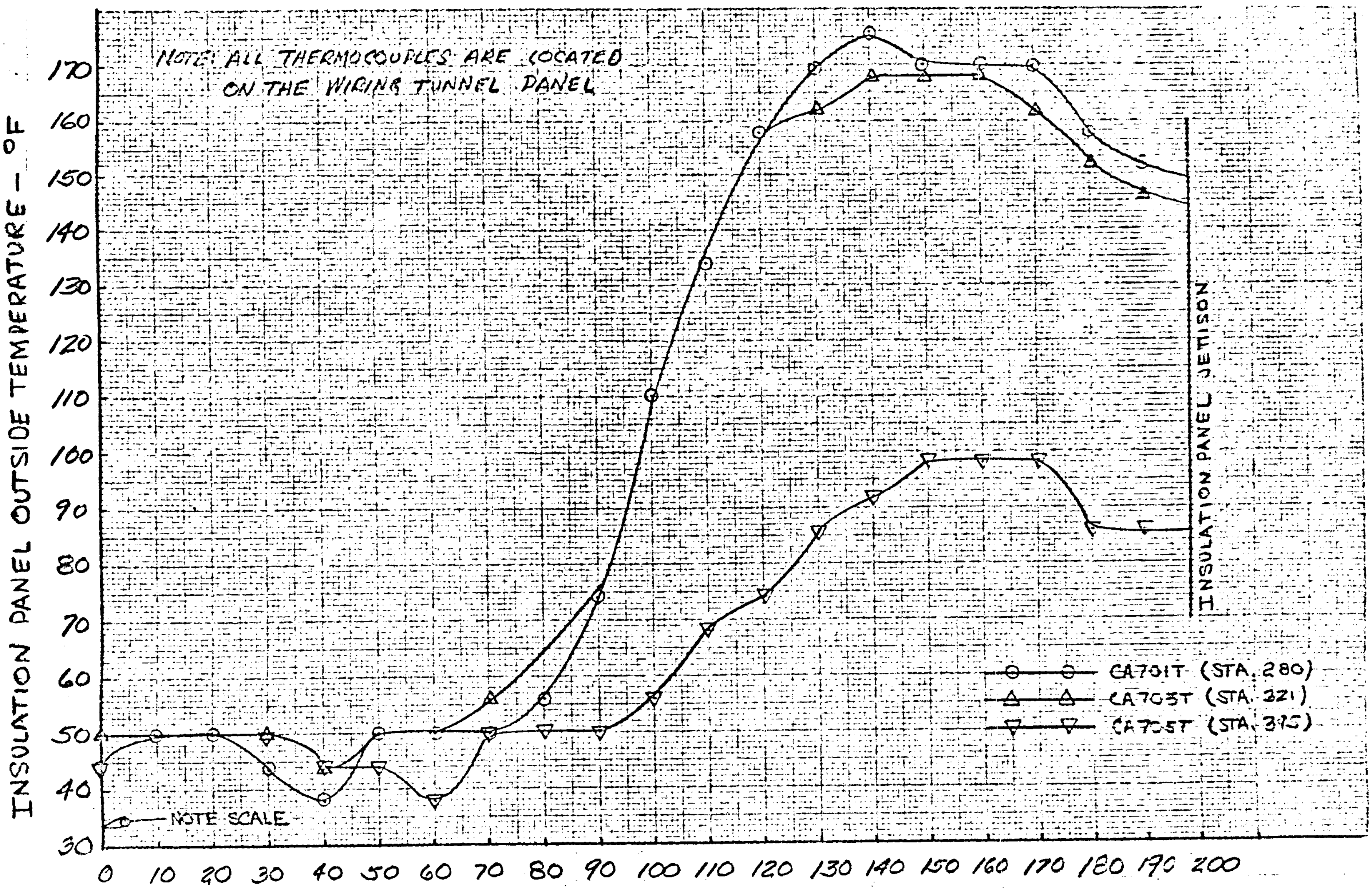


FIGURE 9-14
INSULATION PANEL OUTSIDE TEMPERATURE VS. FLIGHT TIME FOR CENTAUR AC-4

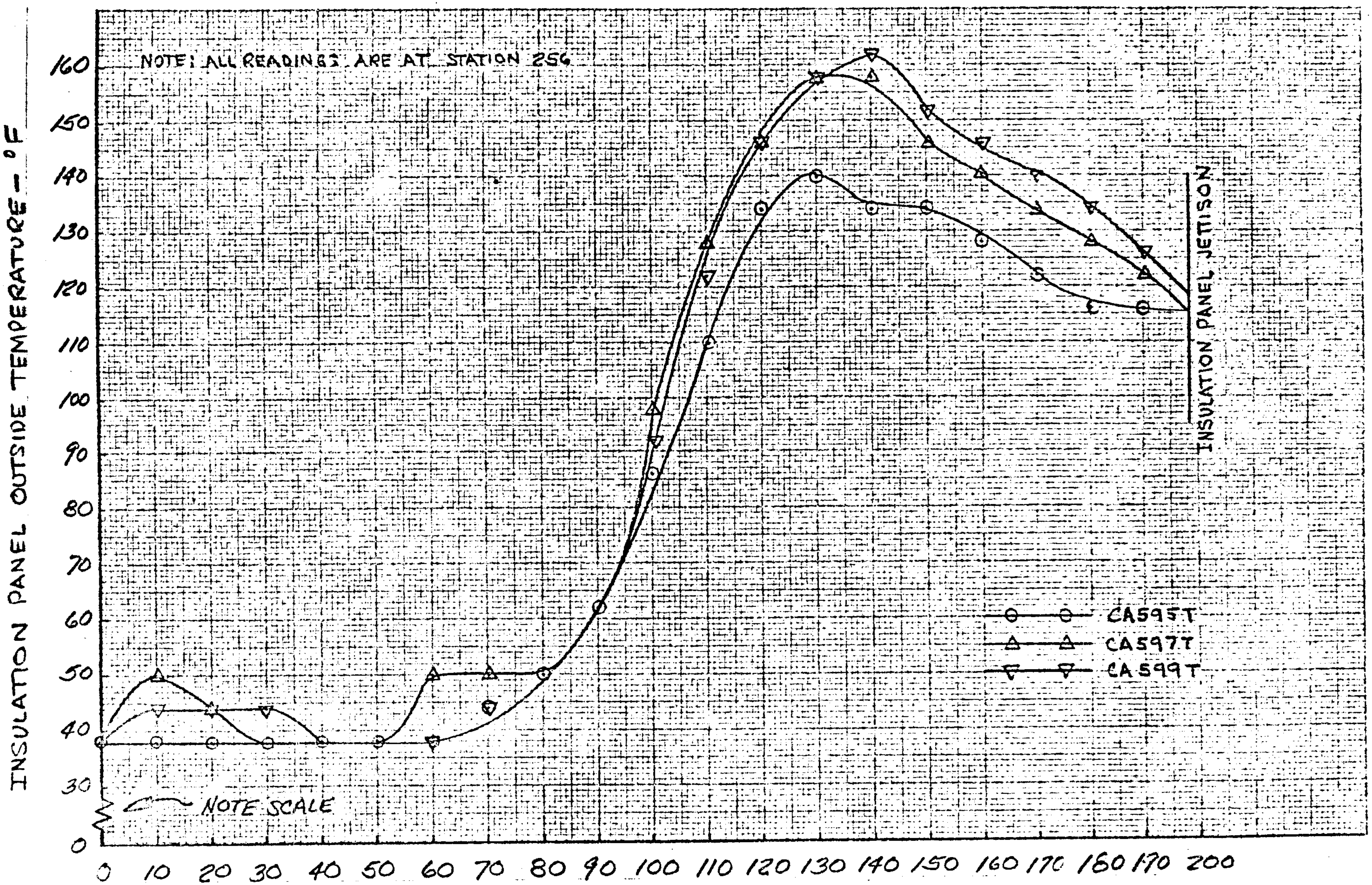


FIGURE 9-15
INSULATION PANEL OUTSIDE TEMPERATURE VS. FLIGHT TIME FOR CENTAUR AC-4

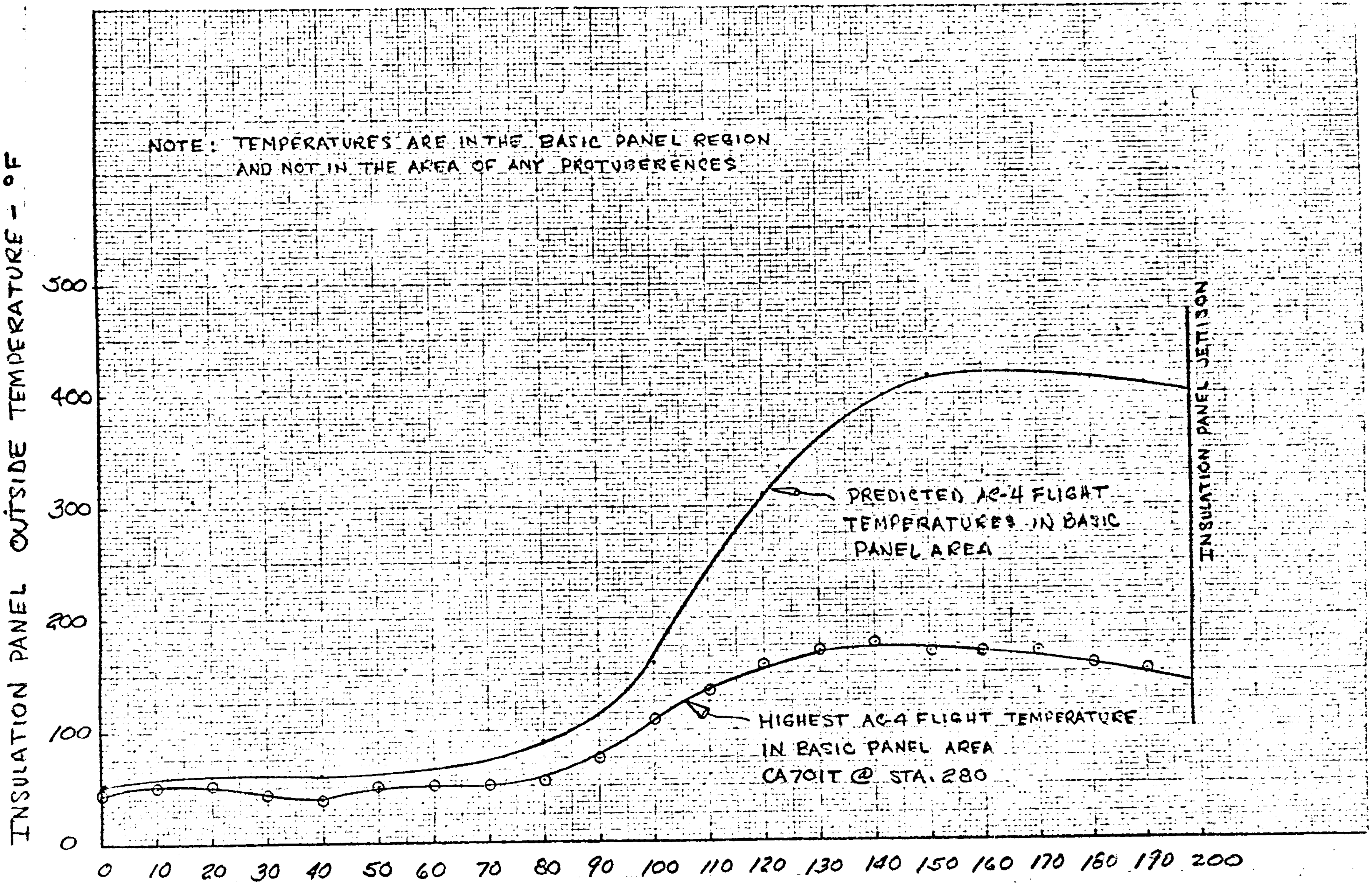


FIGURE 9-16
PREDICTED OUTSIDE INSULATION PANEL TEMPERATURES VS. FLIGHT TIME FOR CENTAUR AC-4

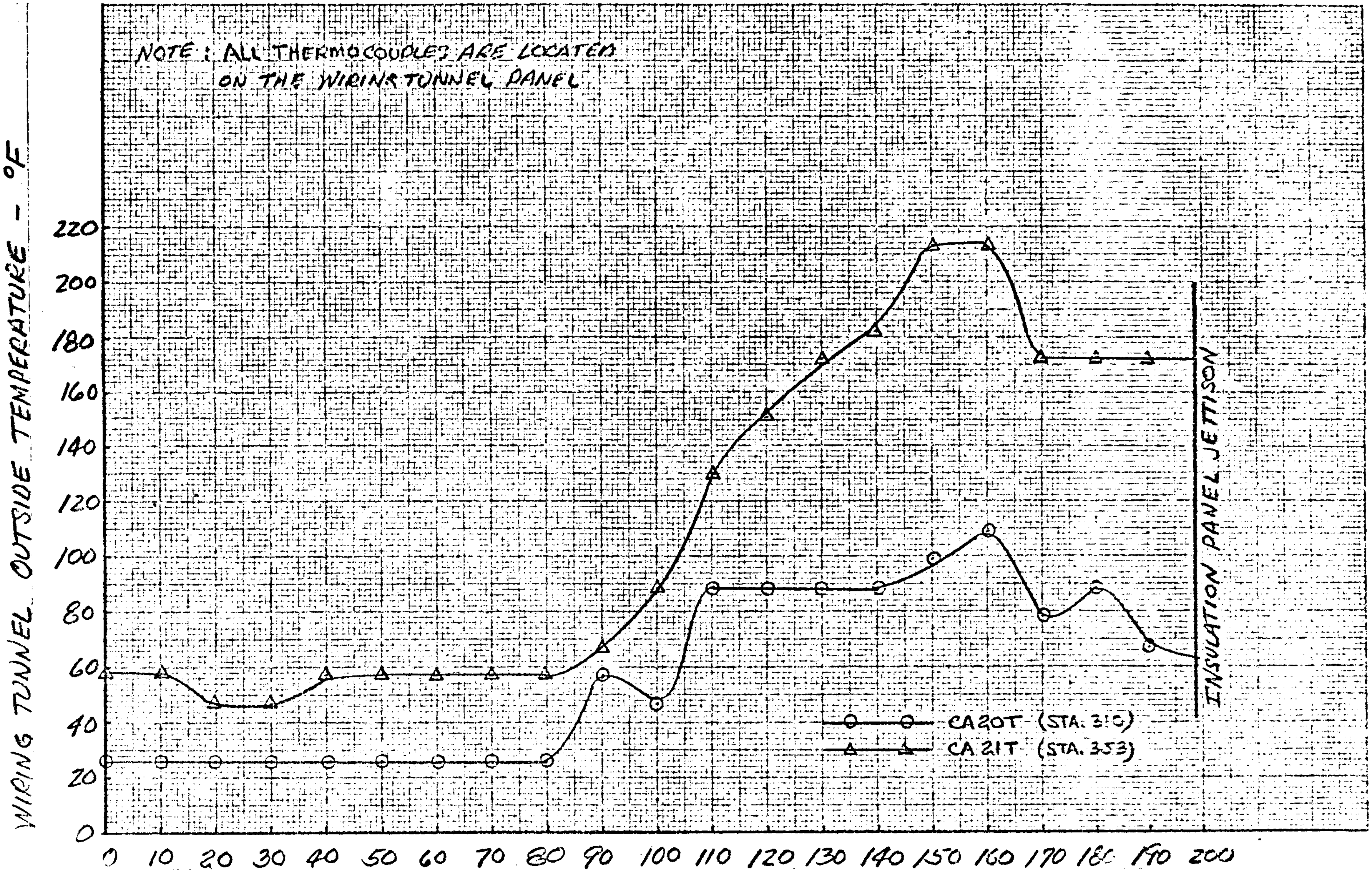


FIGURE 9-17
WIRING TUNNEL OUTSIDE TEMPERATURE VS. FLIGHT TIME FOR CENTAUR AC-4

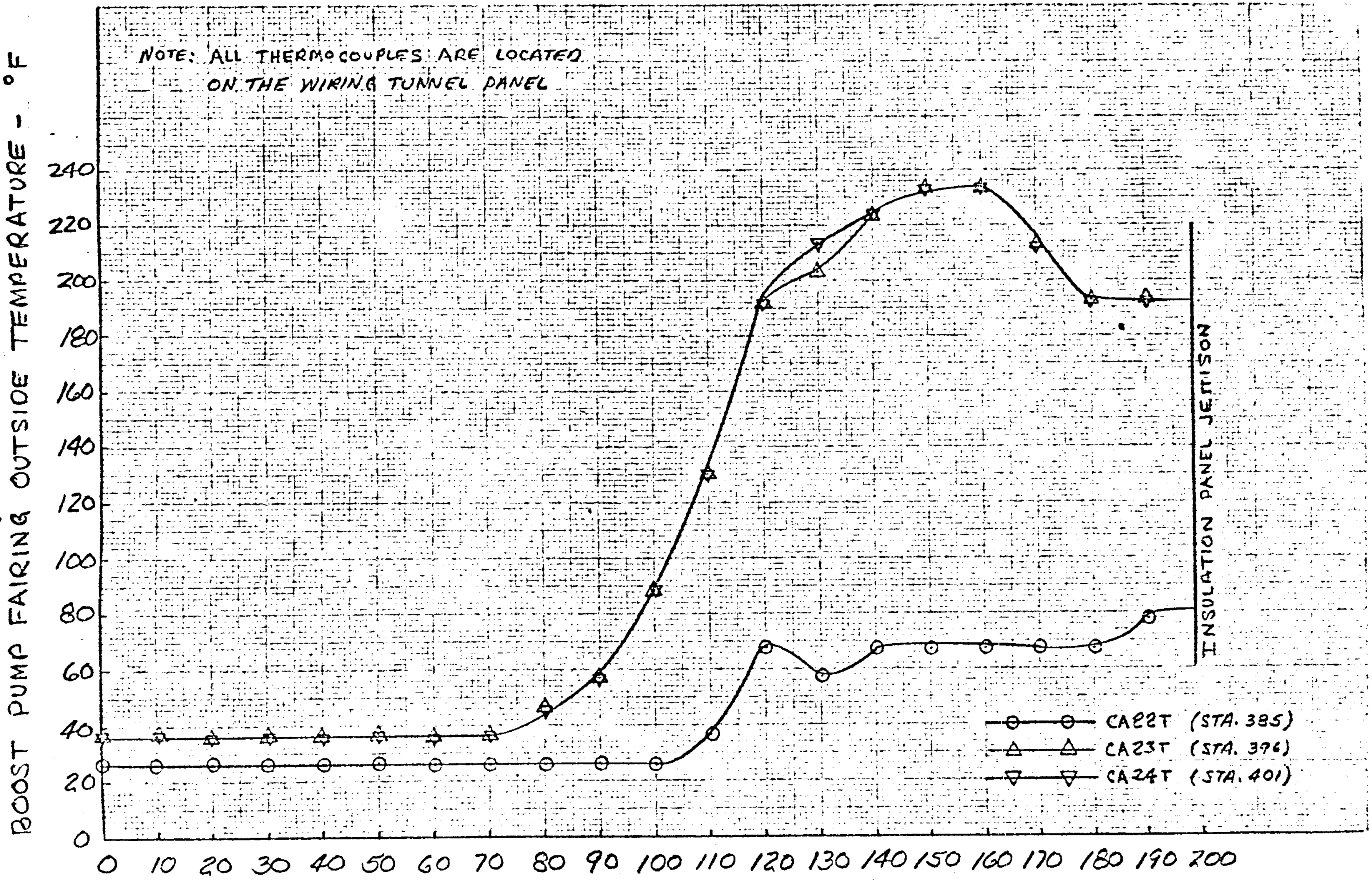


FIGURE 9-18.
BOOST PUMP FAIRING OUTSIDE TEMPERATURE VS. FLIGHT TIME FOR CENTAUR AC-4

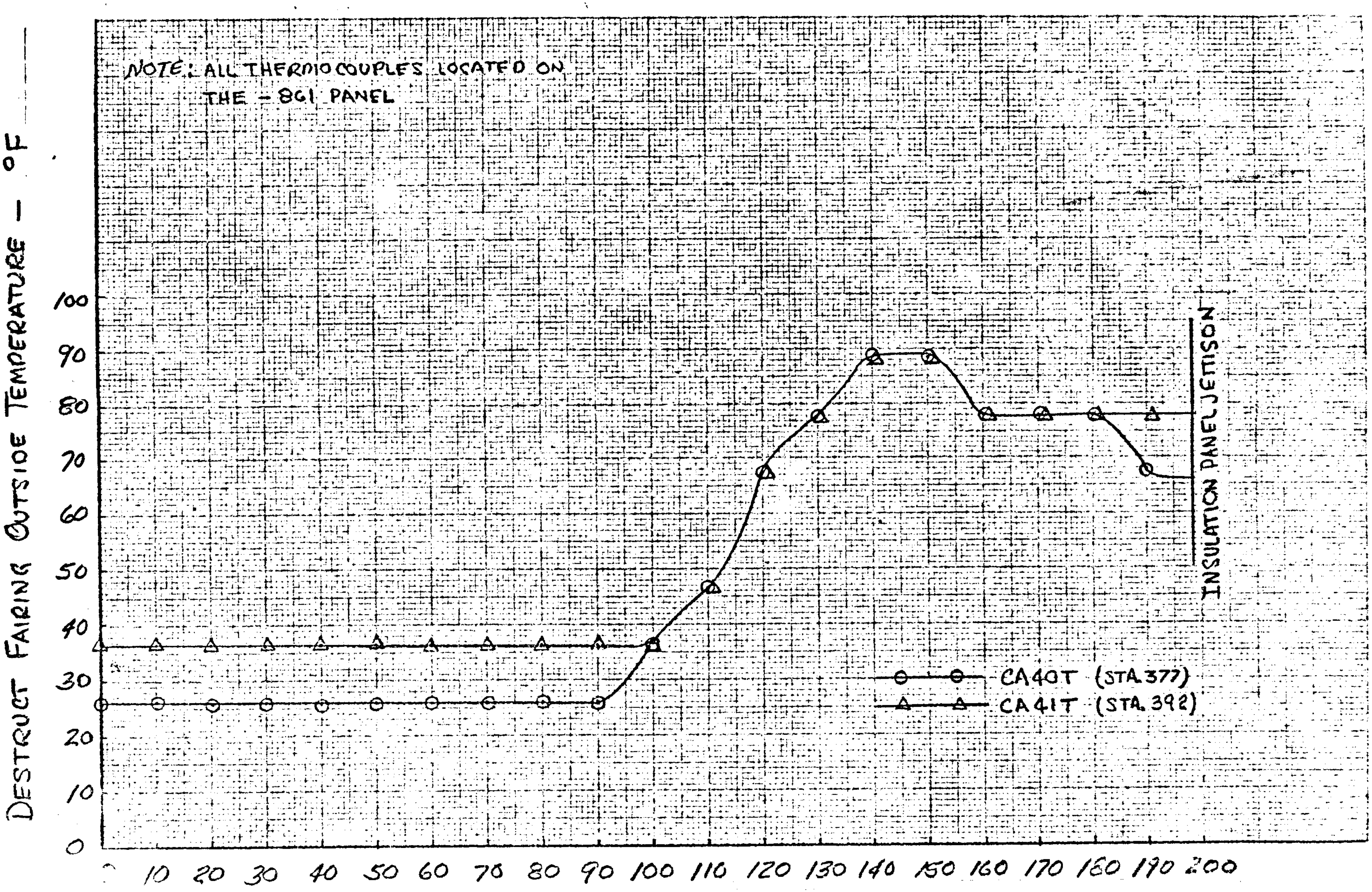


FIGURE 9-17
DESTRUCT FAIRING OUTSIDE TEMPERATURE VS. FLIGHT TIME FOR CENTAUR AC-4

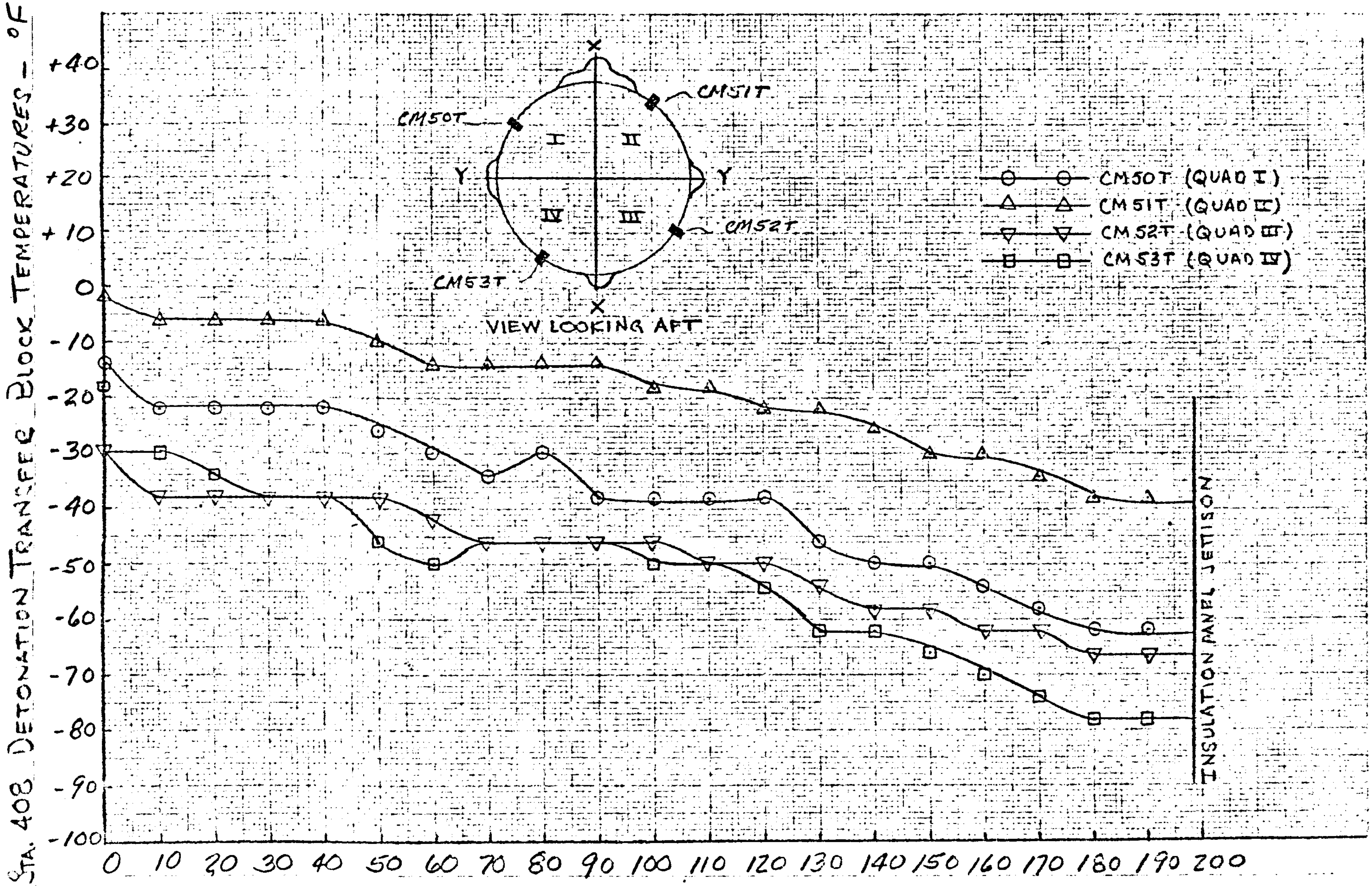


FIGURE 9-20
STA. 408 DETONATION TRANSFER BLOCK TEMPERATURES VS. FLIGHT TIME FOR CENTAUR AC-4

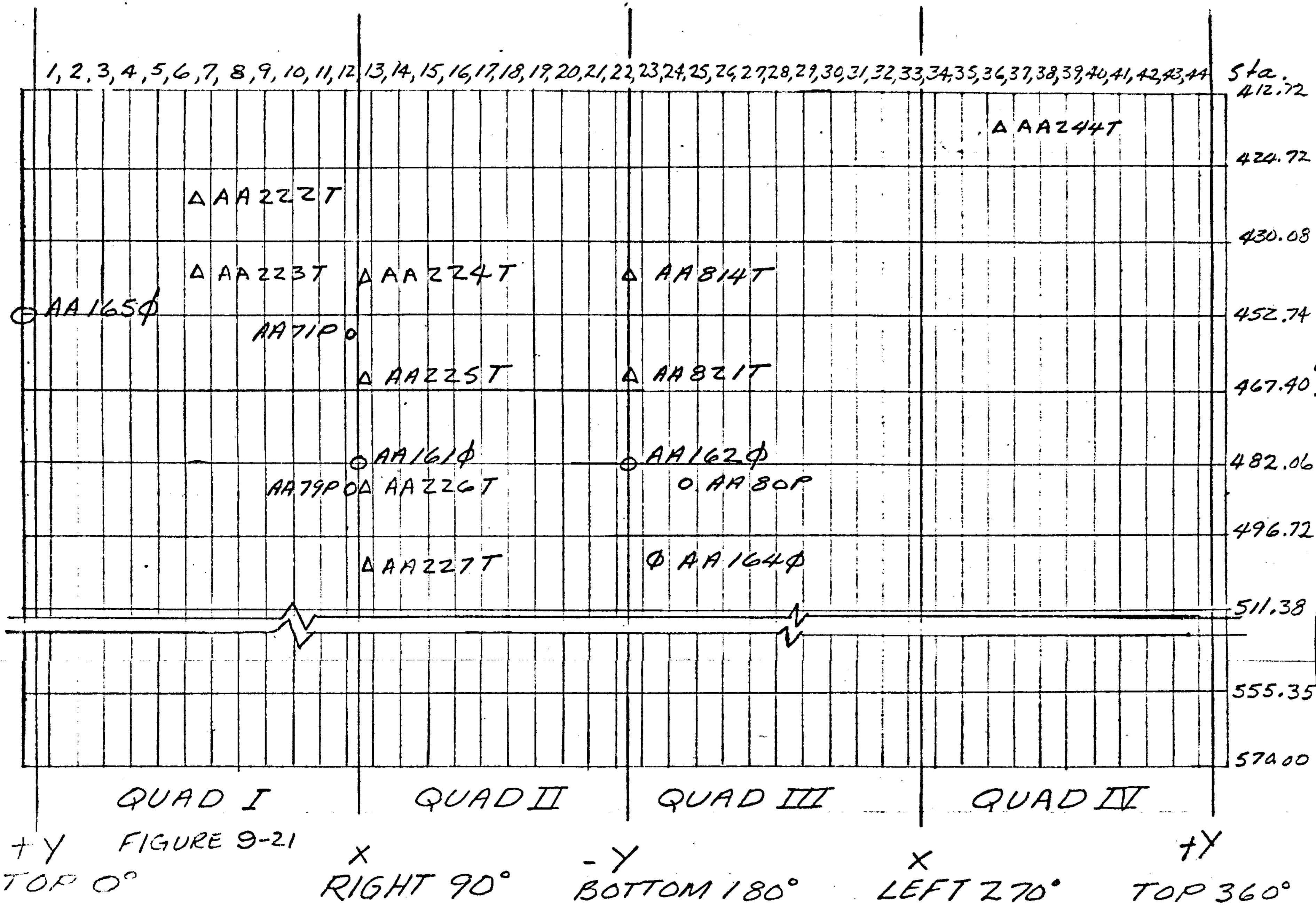


FIGURE 9-21

AC-4 INTERSTAGE ADAPTER INSTRUMENTATION

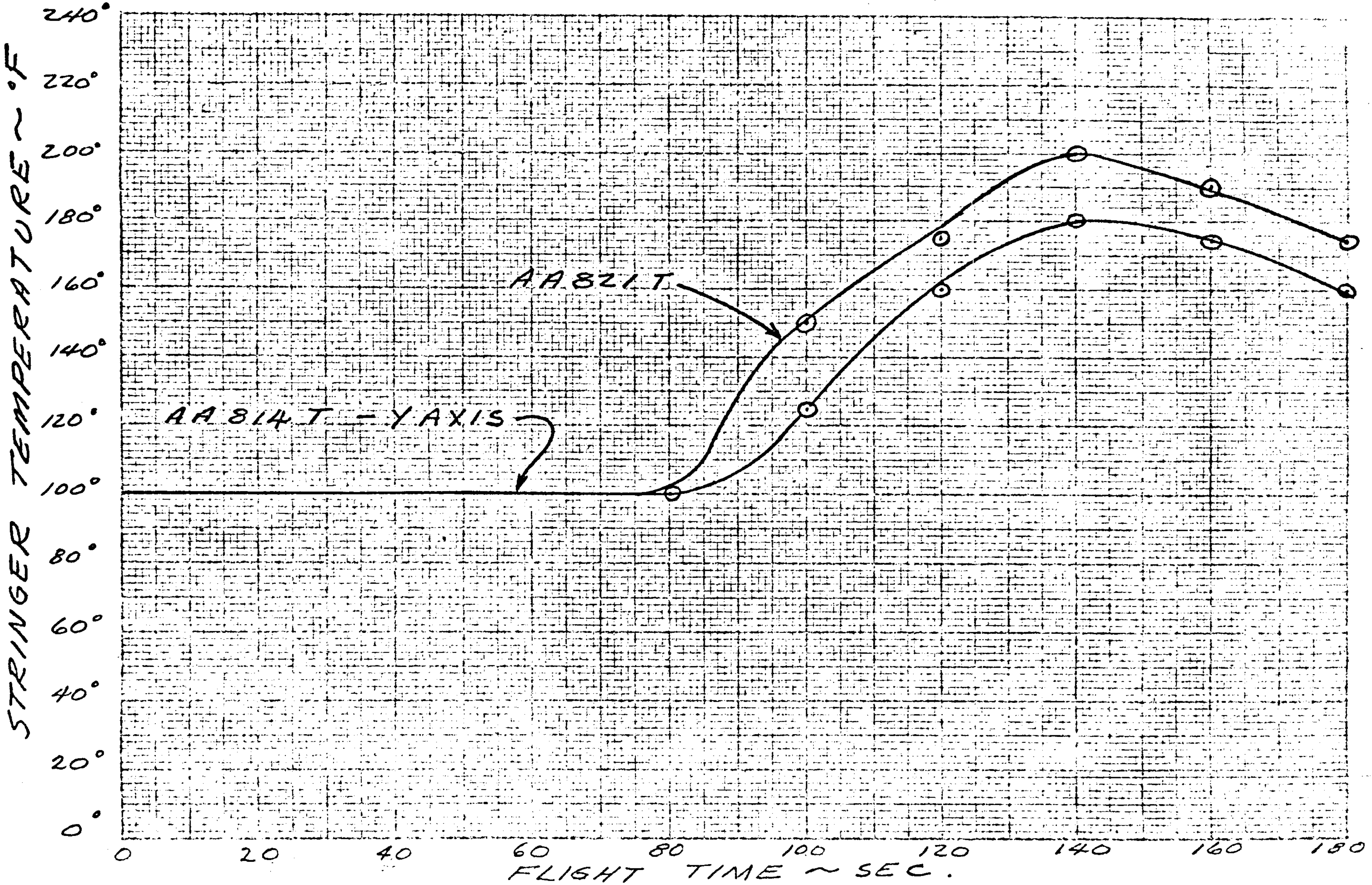


FIGURE 9-22 INTERSTAGE ADAPTER STRINGER TEMPERATURE FLIGHT IX-4

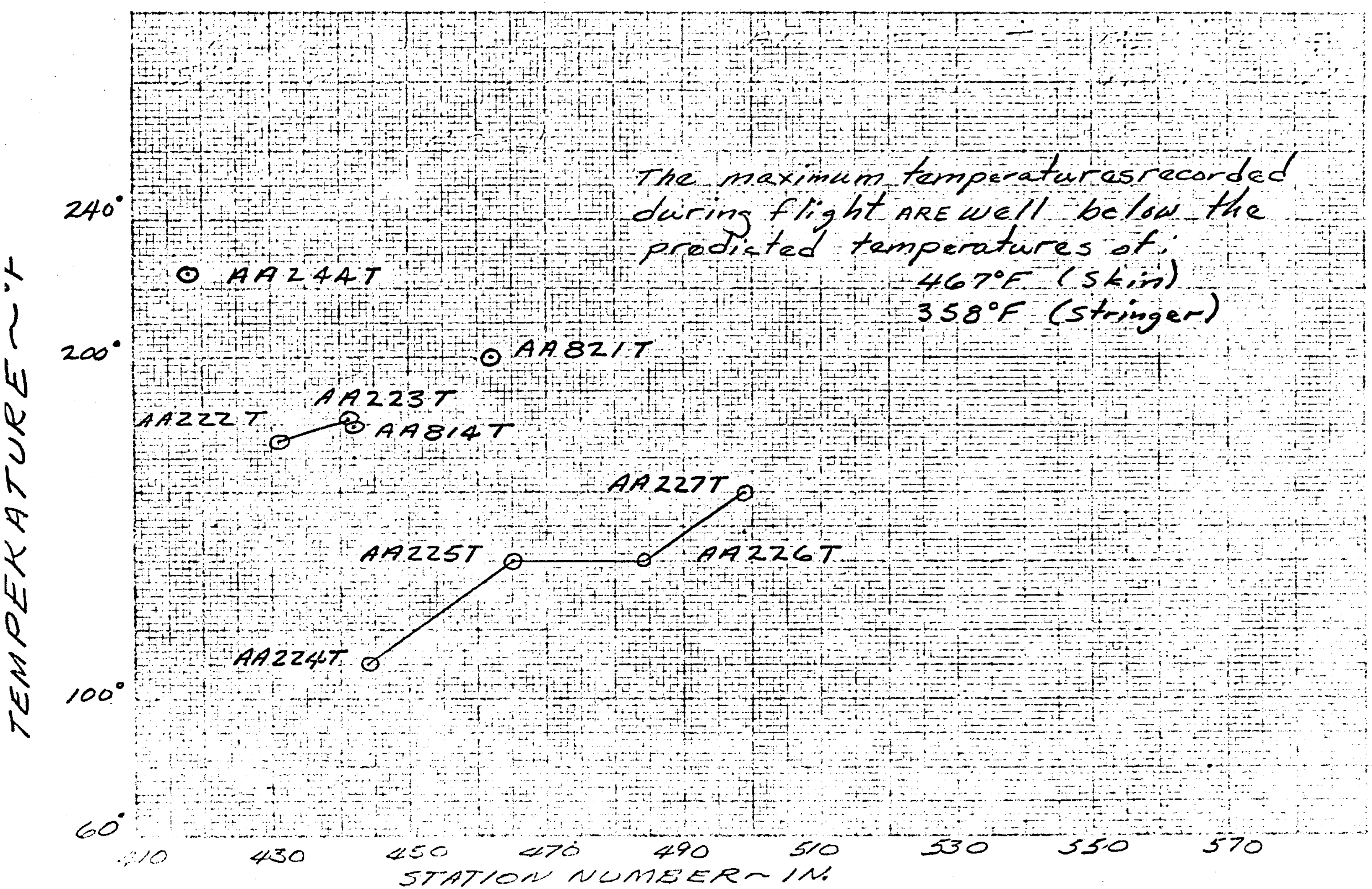


FIGURE 9-23 MAXIMUM INTERSTAGE ADAPTER TEMPERATURE SKIN AND STRINGER LONGITUDINAL VARIATION

FLIGHT HC-4

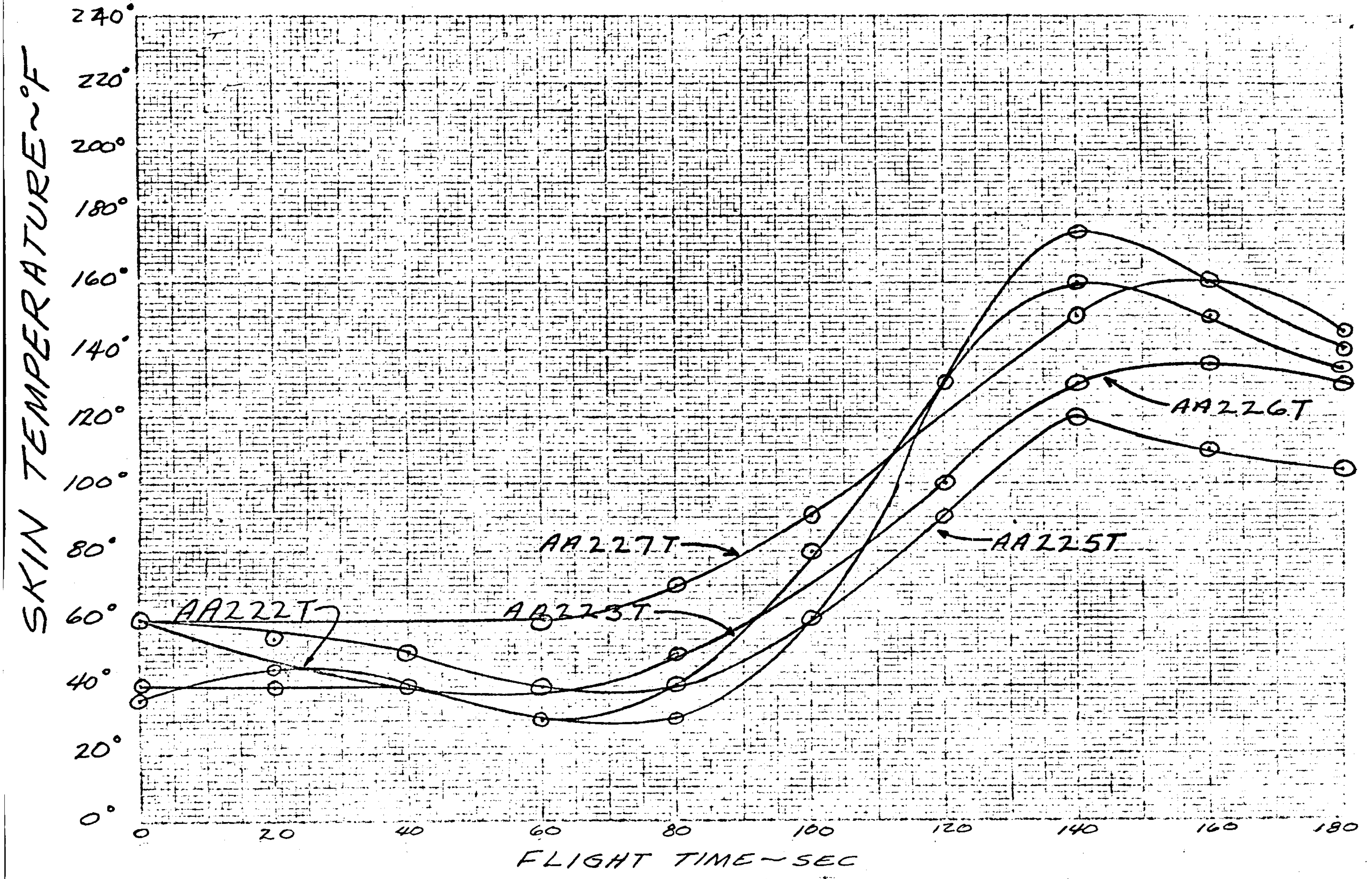


FIGURE 9-24. INTERSTAGE ADAPTER SKIN TEMPERATURE DATA FLIGHT AC-4.

SECTION 10. VEHICLE DYNAMICS AND VIBRATIONS

SUMMARY

During booster phase of flight from launch to BECO low frequency oscillations were quite low and this flight, as in AC-3 flight, was relatively "quiet." Longitudinal and lateral oscillations were very similar to those experienced in AC-3 flight except that a possible longitudinal to lateral coupling took place.

The AC-4 flight vibration environment was similar to both AC-2 and AC-3 and was well within expected levels with the largest vibrations occurring in the interstage adapter.

Low frequency dynamics longitudinal and lateral oscillations during booster phase from launch to BECO were of low level on this flight and compare closely with those experienced on AC-3.

Three forms of longitudinal excitations were again evident as they were in AC-3 flight. Liftoff perturbations from Atlas LOX pressurization instability occurred from launch to T + 12 seconds and were of 12 cps with a maximum of 0.15 g single amplitude. POGO type oscillations took place from T + 80 seconds to T + 92 seconds with a maximum of 0.12 g single amplitude and at 11.5 cps. A one second transient of POGO oscillations at T + 135 seconds and more 11.5 cps POGO from T + 146 seconds to BECO at a maximum single amplitude of 0.12 g occurred. An approximately 90 cps oscillation during BECO transient was evident from the axial accelerometer data and lasted 1/10 second. This perturbation at engine cutoff was at a single amplitude of 0.53 g. The Atlas roll rate gyro data also showed this excitation at the same frequency and amplitude. A bargraph of these occurrences is shown in figure 10-1.

Lateral bending was of very low magnitude being less than that on AC-3 flight. Figures 10-2 and 10-3 show predicted first mode shapes normalized to Centaur rate gyro outputs at station 173 in the pitch and yaw planes at T + 112 and immediately after BECO. As can be seen the deflections are very small. First mode lateral oscillations were not evident on the rate gyro data prior to T + 100 seconds of flight. However, lateral oscillations of a higher modal frequency than the predicted first mode occurred. These were of approximately 6 cps at liftoff and 1/4 g peak-to-peak at Centaur forward end. It is possible that they were induced by longitudinal excitations and coupled into the lateral dynamics. Considerably more analysis will be performed to ascertain the cause and possible effect from these higher modal perturbations.

VIBRATIONS

The vibration environment of the AC-4 flight was similar to both AC-2 and AC-3 (Table 10-2) and was well within expected levels. In general the largest vibrations occurred either at launch or during the transonic region (T + 50 - 80 sec).

The largest vibrations occurred in the interstage adapter during the transonic portion of flight. Measurement AA164 (panel radial Q_1 and Q_2) indicated 96.5 g's peak-to-peak (P-P) after 61.4 seconds of flight (Table 6-1). The largest vibration in the propulsion area was measured by CA 398 (boost pump fairing S407 12R) at 91.6 seconds peak-to-peak value being 13.75 g's. CA392 (wire tun ACC S223.5) indicated the largest vibration in the equipment area (24.9 g's P-P) at 79.5 seconds (transonic region).

A sample spectrum analysis (Bruel and Kojer 1/3 octave analyzer) was performed (40 to 1000 cps) on the output of the accelerometer located on

TABLE 10-2

COMPARISON OF AC-3 AND AC-4 MAXIMUM VIBRATIONS

Location	Measurement number	AC-3 g's P-P	Time, sec	AC-4 g's P-P	Time, sec
Battery mount X-axis	CA26 φ	3.4		5.62	226.6 - 227.6
Near A/P gyro pkg z	CA27 φ	1.2	Transonic	1.83	211.5 - 212.5, nose fairing jettison
UMB ISL ACC S194 Q_1	CA343φ	8.56	Transonic	5.65	211.4 - 212.4, nose fairing jettison
Adapter rad Q_1 and Q_2	AA161φ	42.8	Launch	59.4	151.7 - 152.7, booster jettison
Panel rad Q_2 and Q_3	AA164φ	34.4	86.8 - 87.6	96.5	61.4 - 62.4, transonic

TABLE 10-1

MAXIMUM VIBRATIONS

Location		Measurement number	Time, sec	Max. g's, P-P	Band of data channel frequency, cps	Comments
Interstage adapter z-axis		AA165φ	151.8 - 152.8	8.95	0 - 45	56.5 cps
Equipment located on the interstage adapter (radial)		AA161φ	151.7 - 152.7	59.4	0 - 220	Boost. jet., high freq.
		AA162φ	Only visible def. was at separation	A/C	0 - 1200	Short burp mostly noise
		AA163φ	Signal level too low		0 - 1200	
		AA164φ	61.4 - 62.4	96.5	0 - 2000	High freq., transonic region
Propulsion area*	C-1 Gimbal MT	CA31 φ	47.6 - 48.6	1.88	0 - 1000	T = 531.8 sec data channel was lost
	C-2 Hyd pwr pkg z-axis	CH101φ	339.1 - 340.1	11.2	0 - 800	
	C-1 Hyd pwr pkg y-axis	CH132φ	432.1 - 433.1	7.35	0 - 600	
	C-2 Hyd pwr pkg y-axis	CH133φ	237.7 - 238.7	7.44	0 - 800	MES + 2 sec
	Boost pump fairing S407 12R	CA398φ	91.6 - 92.6	13.75	0 - 600	
	LH_2 duct near y-sect	CA601φ	58.4 - 59.4	3.81	0 - 1000	Transonic region
	LOX boost pump flange	CP556φ	504.8 - 505.8	4.42	0 - 1000	
Equipment area	Battery mount x-axis	CA26 φ	226.6 - 227.6	5.62	0 - 1000	
	Near A/P gyro pkg z	CA27 φ	211.5 - 212.5	1.83	0 - 1000	Nose fairing jettison, 40 cps
	Guid. plat. y-axis 40°	CA89 φ	206.8 - 207.8	1.5	0 - 1000	Short burp lasted 0.05 sec
	Umb. isl. acc. S194 Q_1	CA343φ	211.4 - 212.4	5.65	0 - 600	
	Wire tunnel acc. S223.5	CA392φ	79.5 - 80.5	24.9	0 - 600	Transonic region
	Payload ring S130/120	CA459φ	198.5 - 199.5	13.48	0 - 220	Excessive cross talk on data channel
	LH_2 B/O valve	CA265φ	91.7 - 92.7	35.22	0 - 600	

*Power spectral density analysis was performed, see Figure 6-1.

the C-1 engine gimbal mount (CA31). The time of analysis was from 47.6 seconds after the launch to 48.6 seconds. The vibration environment consisted of both sine and random; the overall level was two orders of magnitude below the qualification level. Largest energy concentration was 0.0036 g^2rms/cps at a frequency of 400 cps (Fig. 10-4).

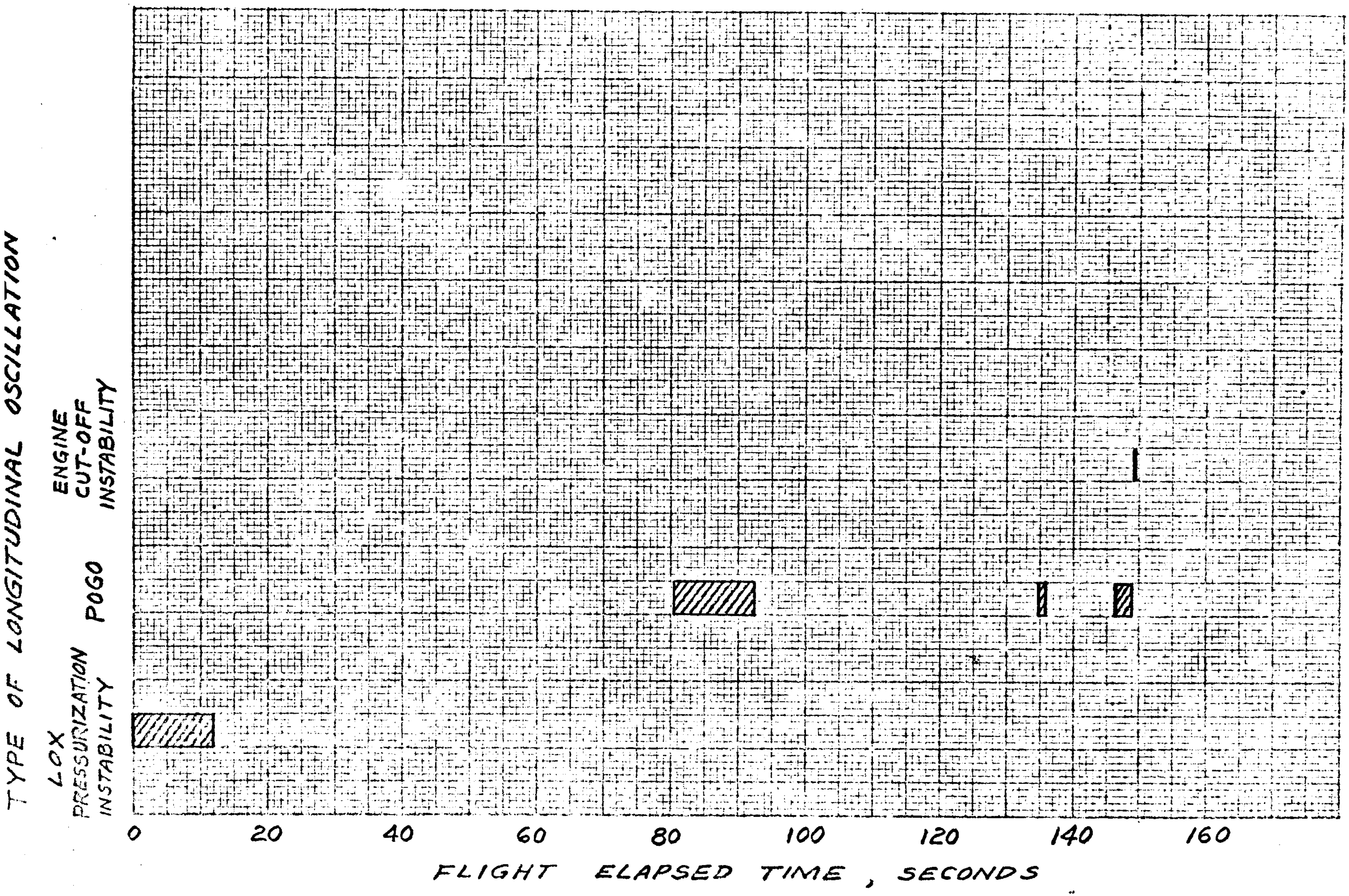


FIG. 10-1 LONGITUDINAL OSCILLATION OCCURRENCE

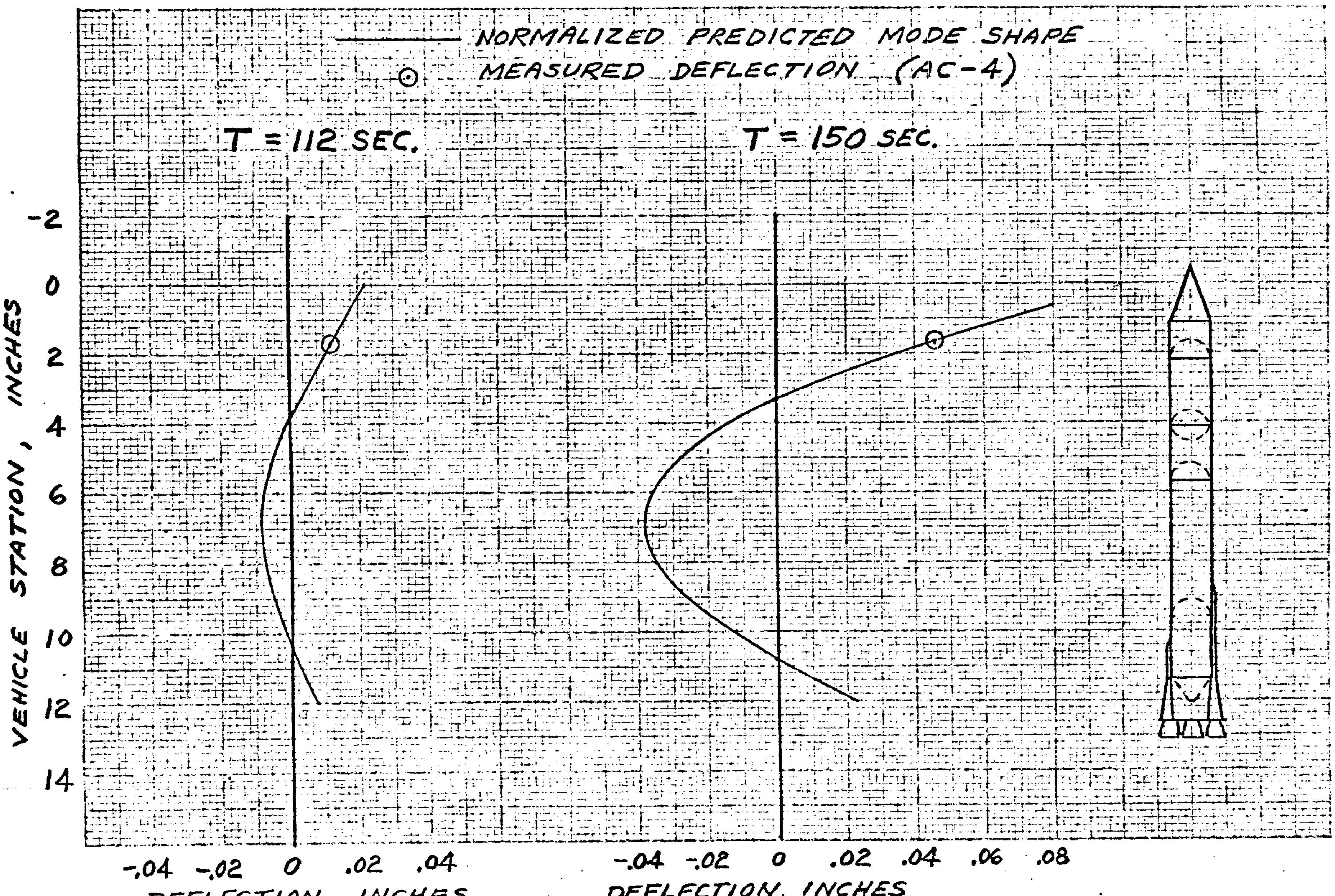


FIG. 10-2 BENDING MODE AMPLITUDES , PITCH (YZ) PLANE, 1ST MODE

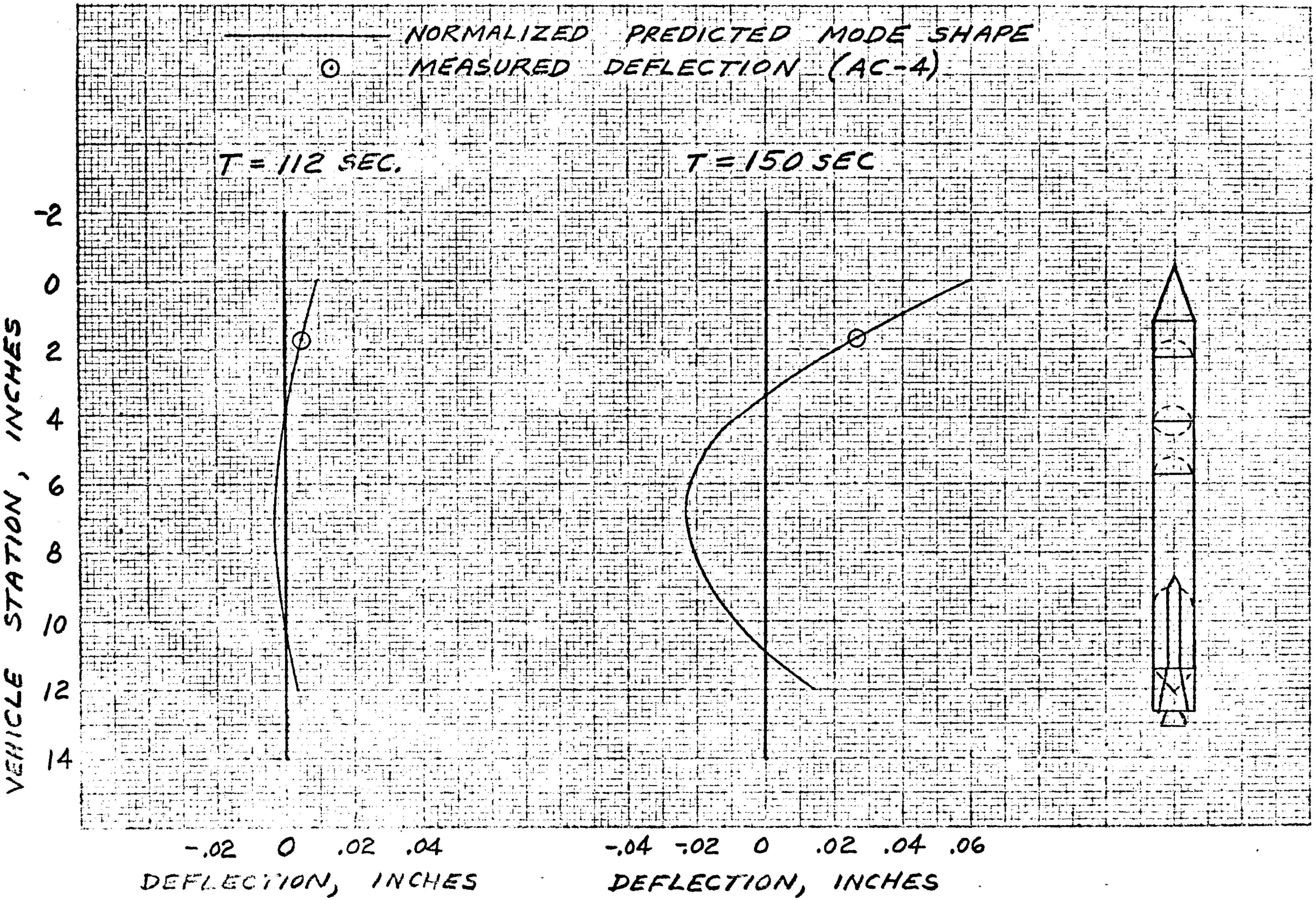
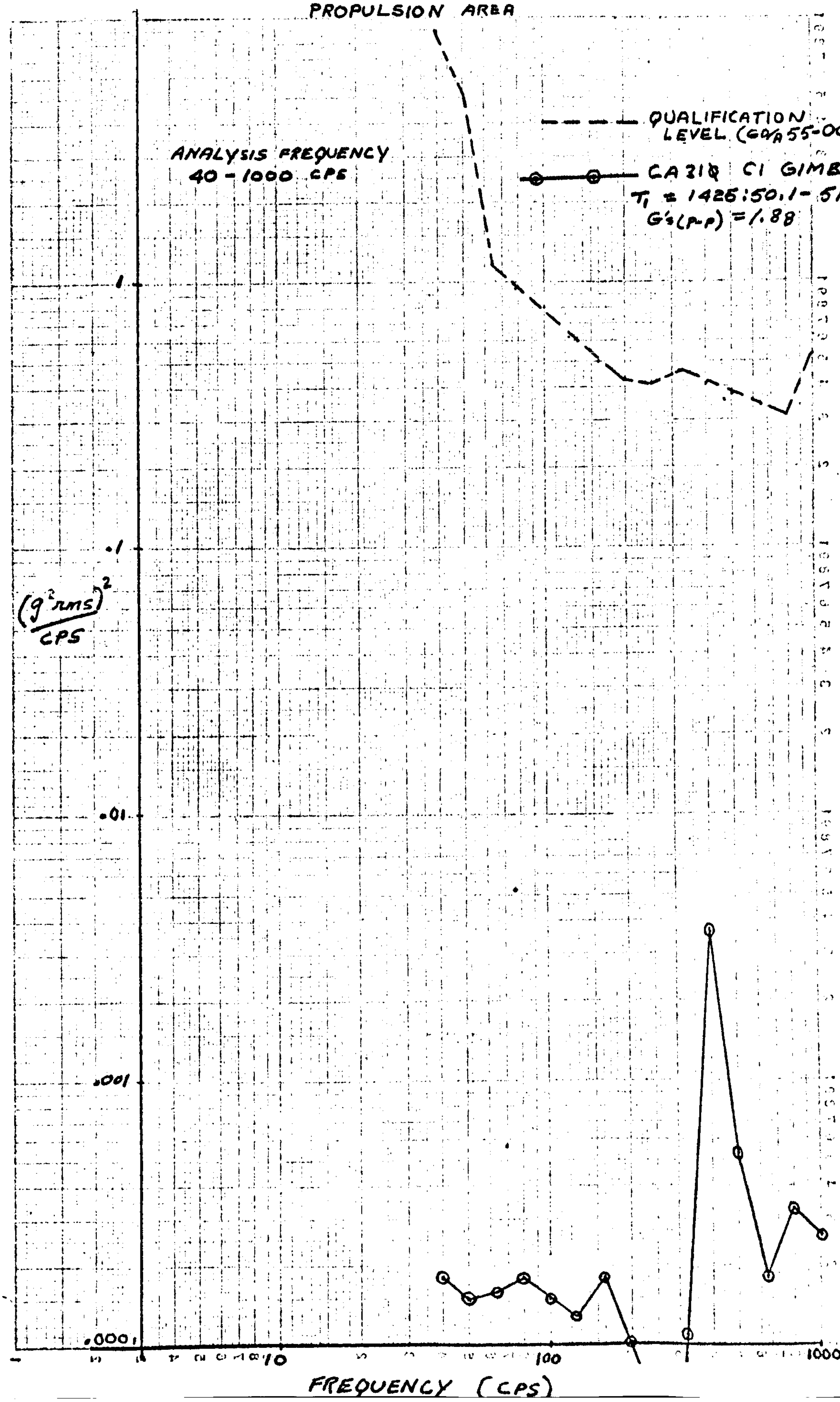


FIG. 10-3 BENDING MODE AMPLITUDES, YAW (XZ) PLANE, 1ST MODE

FIGURE 10-4

AC-4 VIBRATION LEVELS

PROPULSION AREA



SECTION 11. GUIDANCE

The Centaur guidance system (MGS number 24) was calibrated on F-1 day and power was applied to the system throughout the night. On F-0 day the system was recalibrated and the shifts in "d" parameters were well within the run-to-run specifications. At T-90 minutes a momentary dropout of inverter power caused the guidance power failure indicator to illuminate. The computer was recycled off-on and "D" and "J" terms were verified. There was no change in value of the terms which are stored in the computer temporary storage. Real time data from the KSC computer verified the U and V gyro constant torque terms (D10 and D13). The W accelerometer terms were verified by a 10 minute count of the ΔV's. The azimuth optical alinement system performed satisfactorily during the AC-4 countdown.

The following table includes a list of the individual packages comprising MGS number 24, their serial numbers, and the skin temperatures.

		T-5 second, ^{o}F	T-1000 second, ^{o}F
Platform	S/N G7	66.1	85
Plat. Elec.	S/N G8	48.2	70
Sig. Cond.	S/N G8	40.0	46
Computer	S/N 007	42.4	73
Coupler	S/N G12	47.2	81
Comp. I/O		35.0	73

The temperatures prior to launch are significantly lower than those measured on AC-3, although they are within the specified limits. The inertial component heaters were controlling throughout the flight. There is no indication of maximum heater current and no anomalies were apparent on the available telemetry signals.

The airborne computer does not generate steering signals during the booster phase of flight; therefore, the resolver chain input signals are maintained 0 volt. At BECO + 5 the steering signals are generated which is indicated by the U and W resolver chain inputs increasing to 9.20 and 3.78 VAC, respectively. The V resolver chain input remained at 0 volt indicating no cross range change throughout the first 500 seconds of flight. The X and Y resolver chain outputs shift slightly at T + 158 indicating guidance has been enabled and is now sending steering signals to the Atlas autopilot. The resolver chain outputs do not null out which would normally indicate the vehicle was not steering to the proper vector; however, the analog data is drifting and should be rerun in order to determine whether the guidance system provided proper attitude control during Atlas sustainer and Centaur burn.

At T - 7.6 seconds the U, V, and W gyro torquing signals change significantly indicating the guidance system has gone to the inertial mode. At T + 214 the W torquing trace shifts indicating an equivalent change of 1^{o} per hour in W torquing; however, the digital data does not confirm this change in torquing rates. Using the in-flight torquing equations and the "d" values obtained from F-0 day calibration, it was determined that a 3 g thrust acceleration in the W direction would be necessary in order to change the W torquing rate 1° per hour. A histogram of the ΔV_W counts is not available to confirm such an acceleration occurring. It is significant to note the change in torquing occurs at nose fairing separation. There is also a change in W torquing equivalent to 0.3° per hour at the time insulation panels were jettisoned. The U and V torquing traces did not change at either of the occurrences. Figures 11-1 through 11-3 are plots of the U, V, and W torquing pot inputs from the computer for the first 450 seconds of flight. An attempt was made to plot the torquing pot outputs but the analog data must be rerun for a better evaluation. Figures 11-4 to 11-6 are plots of the thrust velocities obtained from the digital data.

Telemetry signals of the gimbal torque motor inputs do not indicate any large transients during the Atlas or Centaur phases. At T + 4 gimbal number 1 reflects the start of roll program and at T + 15.4 gimbal number 3 begins to drive in response to the pitch program. Gimbals number 2 and 4 indicate roll gimbal uncaging at T + 53.4; whereas the roll gimbal uncaging signal went off scale at T + 53.1. Both of the indications are close to the nominal time of T + 53. From T + 144 to BECO gimbals numbers 2, 3, and 4 oscillate at 1.6 cps which is indicative of Atlas LOX sloshing. Between BECO and SECO gimbal number 2 oscillates at a frequency of 0.75 cps with a p-p amplitude of 1 volt. At MES gimbals numbers 1 and 3 begin to oscillate at a frequency of 0.20 cps which is characteristic of rigid body oscillation. From MES to loss of telemetry gimbal number 2 oscillates with a p+p amplitude of 1 volt and a frequency of 0.50 cps which is characteristic of rigid body roll.

Further analyses of telemetry and digital data must be made in order to determine how well the guidance system performed. Since this was the first closed loop flight a comparison should be made between torquer pot inputs and outputs from the time guidance was enabled. An analysis of the resolver chain outputs on the telemetry reruns will be made to determine whether or not the system steered to the proper vector.

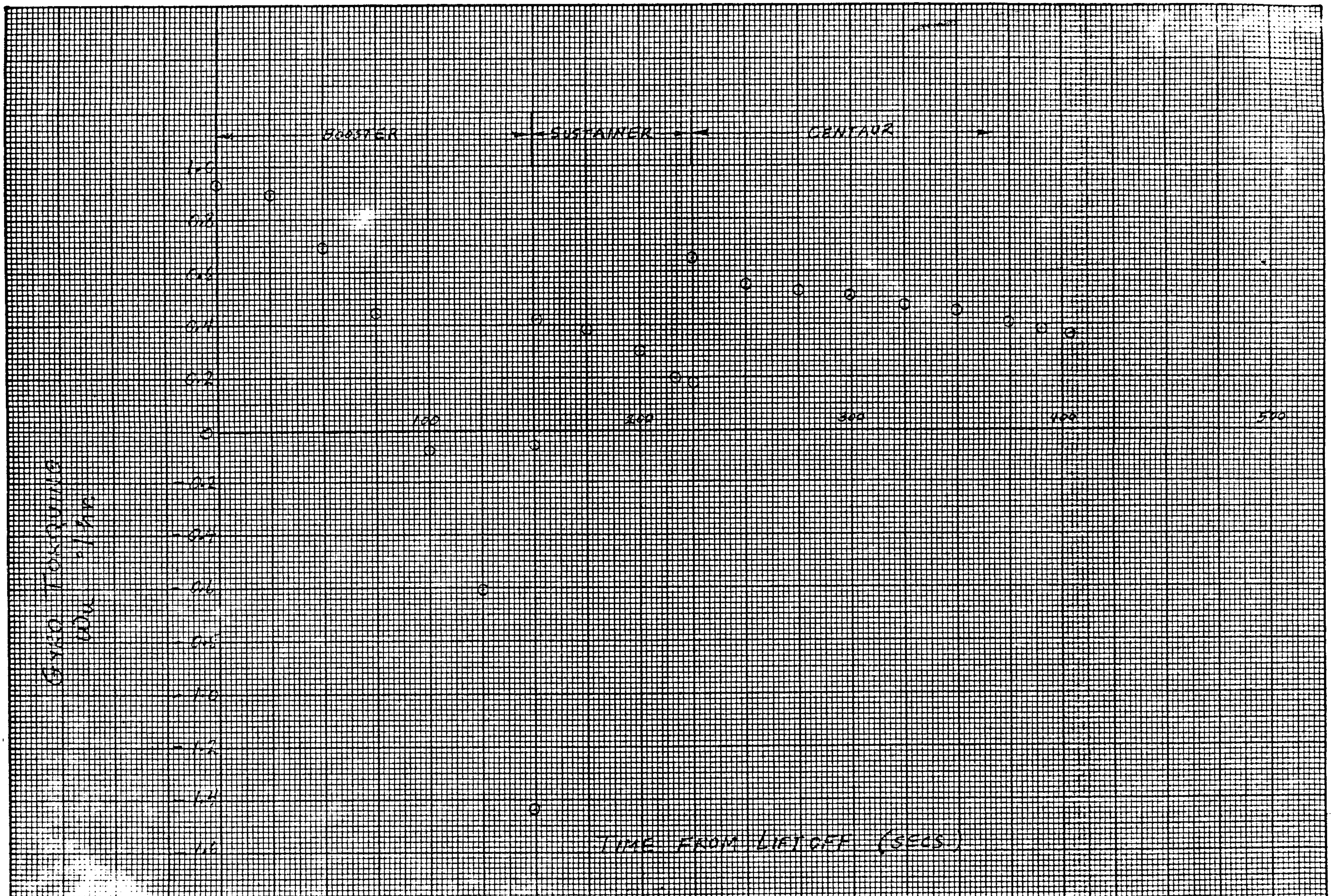


Fig 11-1 Guidance System Gyro Torquing Rates

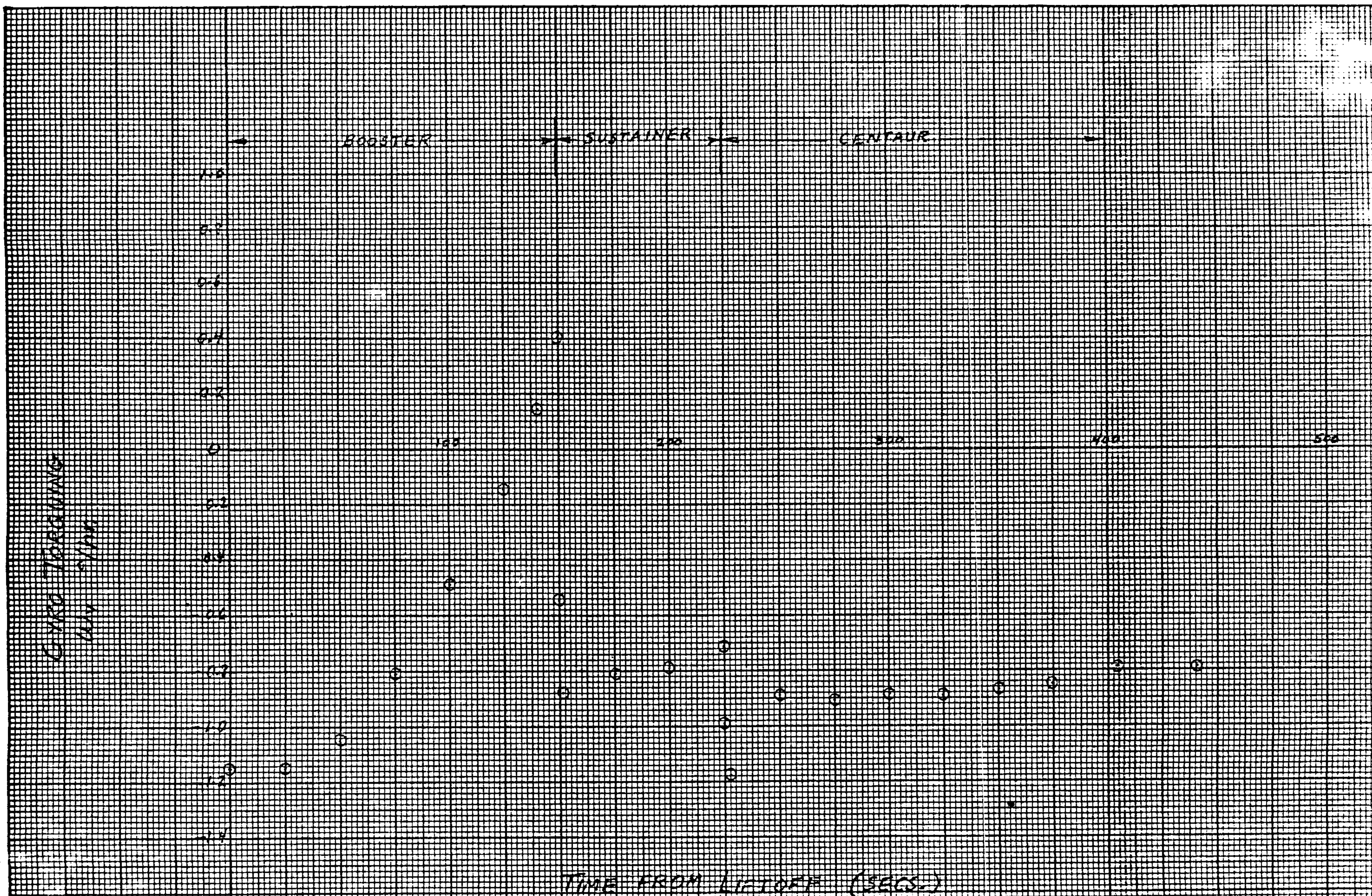


Fig 11-2 Guidance System Gyro Torquing Rates

Fig II-3 Guidance System Gyro Torquing Rates

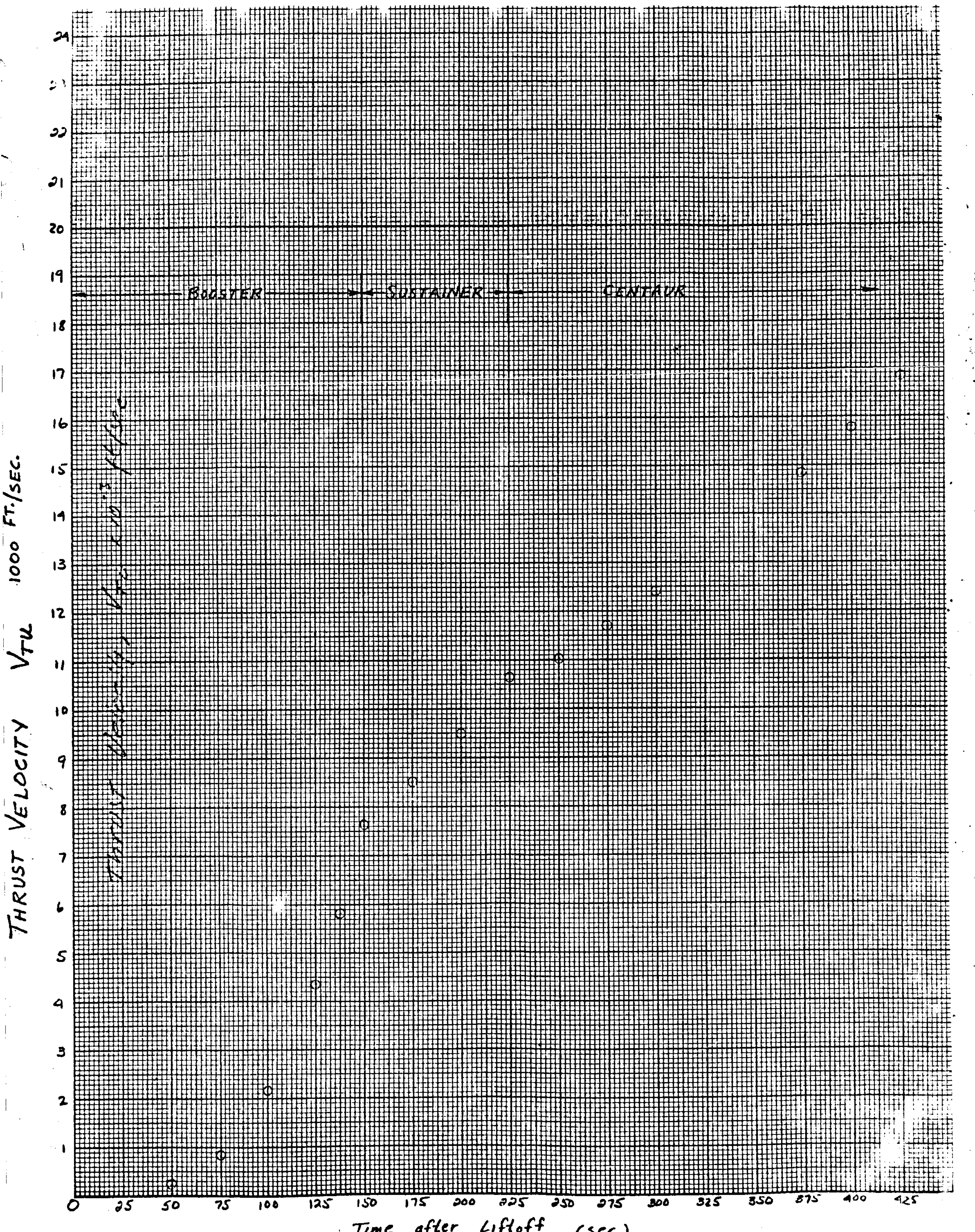


FIGURE 11-4 Thrust Velocity during initial AC-4 FLIGHT

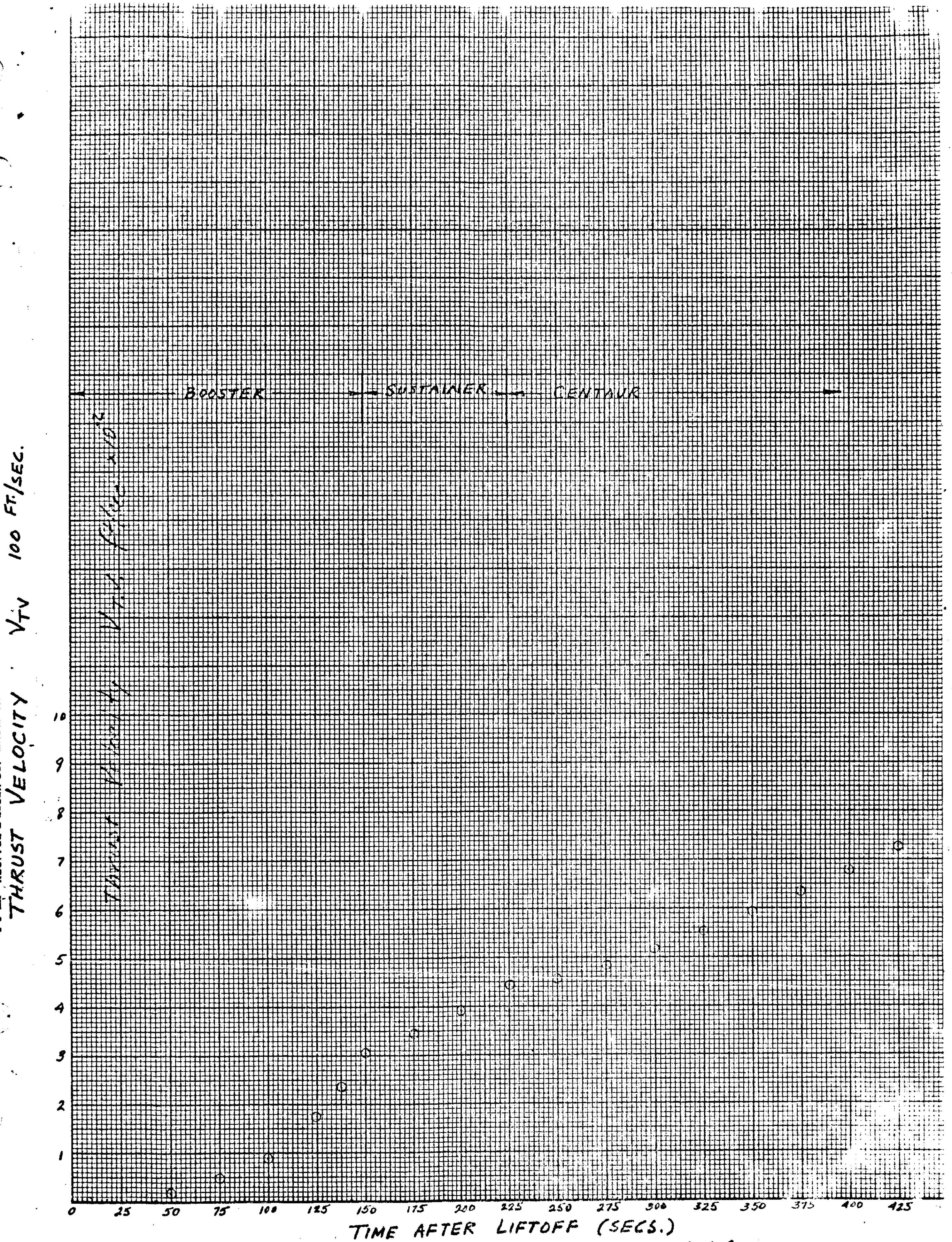


FIGURE 11-5 Thrust Velocity from initial AC-4 FLIGHT

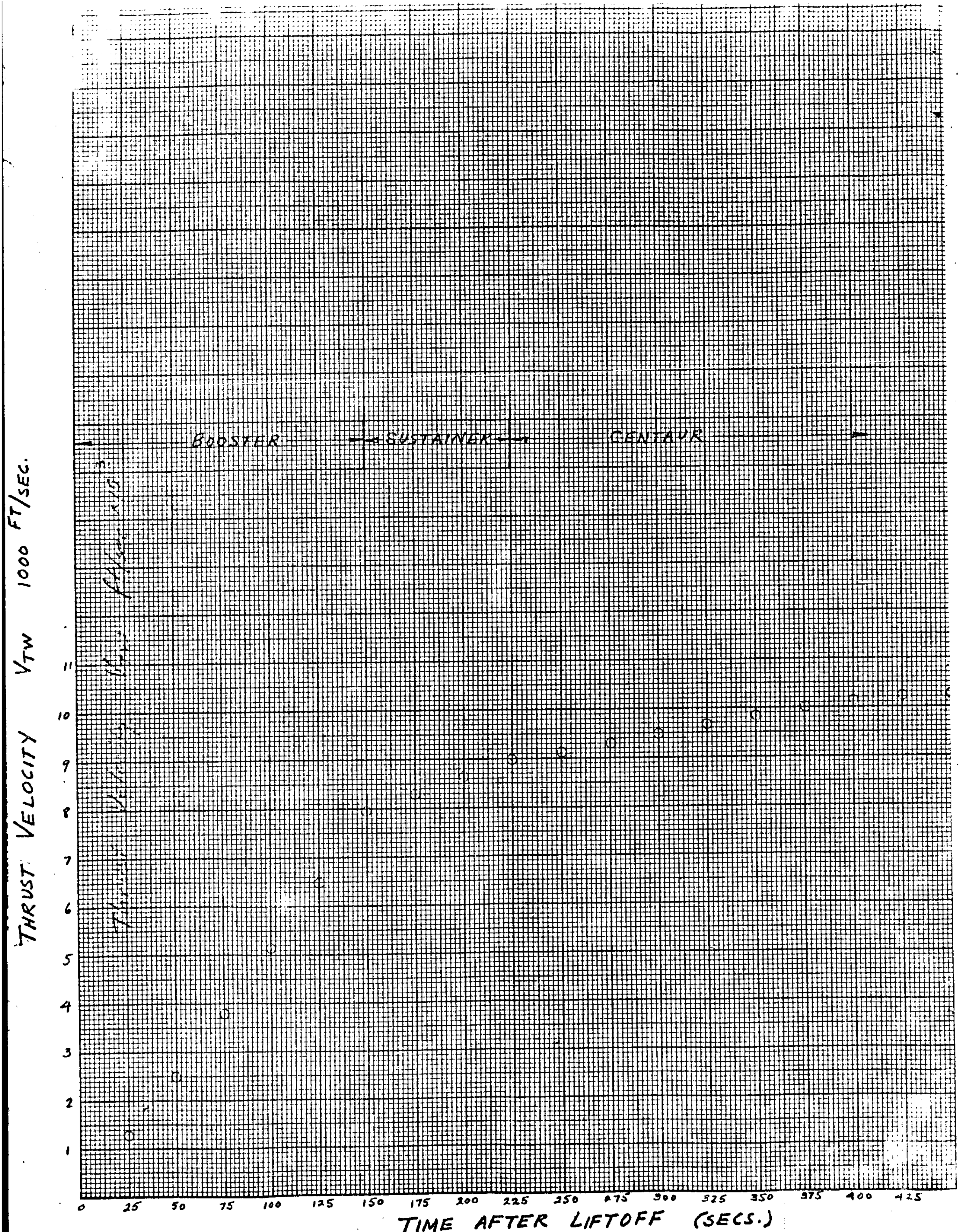


FIGURE 11-6 – Thrust Velocity during Initial AC-4 Flight

SECTION 12. FLIGHT CONTROL

SUMMARY

Preliminary analysis of telemetry data indicated that AC-4 control system performance was satisfactory until T + 840 seconds at the start of LH_2 venting during the first coast period. Observed responses during Atlas boost and Centaur first burn followed closely predicted limit cycle frequencies and amplitudes.

ATLAS

At lift-off, a high frequency vibration near the natural frequency of the second bending mode (35 rad/sec) was observed in both pitch and yaw rate gyros. Peak-to-peak amplitudes averaged 0.1° per second in both planes and decayed in approximately two seconds after lift-off. Similar oscillations have been observed in the AC-3 flight.

Following lift-off, the Atlas booster flight was smooth through the entire atmospheric ascent. No transients or oscillations of unusual magnitude were observed from telemetry until BECO when the Atlas roll rate and pitch rate gyros showed a diverging oscillation at the limit cycle frequency of the Atlas LOX sloshing mode. The diverging oscillation started at approximately 7 seconds prior to BECO, reaching peak-to-peak rates of 3.47° per second in roll and 1.18° per second in pitch at a frequency of 9.8 radials per second as telemetered from the Atlas rate gyro. These oscillations discontinued with the initiation of BECO. Figure 12-1 shows the time history of the vehicle responses at BECO.

Root locus analysis had predicted an unstable limit cycle for the Atlas LOX sloshing mode prior to BECO. Analysis gives the engine limit cycle amplitude at approximately 0.82° peak-to-peak. Figure 12-1 shows that the booster number 1 and 2 engines at a maximum peak-to-peak amplitude of 0.8° and 1.1°, respectively, indicating that if the BECO discrete had been delayed, further divergence would have stabled out near these amplitudes.

The coupling into the roll plane, however, had not been predicted by analysis, but has been observed on the AC-3 flight. Figure 12-2 shows a comparison of roll rates as measured by the Centaur roll rate gyros. Prior to BECO, the primary difference in the autopilot configuration is the operating gain (K_a) of 1.0° per degree; an increase of approximately 15 percent over the AC-3 position gain of 0.87° per degree. Consequently, larger amplitudes are to be expected over AC-3 responses. The table below shows a comparison of autopilot, engine, and sloshing parameters between AC-3 and AC-4.

		AC-3	AC-4
BECO	BECO discrete	147.8 sec	148.8 sec
K_a	Position gain	.87 deg/deg	1.0 deg/deg
δ	Engine limit cycle amplitude (peak-to-peak)	.70 deg	.82 deg
W_{ALOX}	Atlas LOX limit cycle frequency	9.8 rad/sec	9.8 rad/sec

The pitch/roll coupling appears to indicate a circular slosh phenomena occurring in the Atlas LOX tank. Telemetry shows no diverging oscillations in the yaw plane which might be expected with this type of sloshing. However, the primary source of booster-phase roll control (booster engines gimbled differently in yaw/roll) are complemented by a sensitive vernier roll control moment which effectively reduces roll limit-cycle amplitudes caused by booster engine dead zones. Also, roll signals into the booster vernier engines are not led through an integrator-filter feedback network. As a result, this autopilot configuration tends to null out small oscillations in roll with the vernier engines.

Following BECO, telemetry shows small oscillations in rigid body, first modal bending, and Atlas LOX sloshing. The jettisoning of insulation panels and nose fairing excited the first bending mode as observed from the Centaur yaw rate gyros. Peak-to-peak amplitudes were very small (0.1°/sec). No oscillations were observed in pitch due to the above events. Figure 12-4 shows a plot of predicted and flight test frequencies from liftoff to SECO. The predicted frequencies are limit cycle frequencies as calculated by time-slice studies using root-locus techniques. Flight test frequencies are those observed from telemetry of yaw and pitch rate gyro outputs.

SEPARATION

SECO/VECO discrete was commanded at T + 224.3 seconds. During Atlas/Centaur separation, T + 226.7 seconds vehicle rates were 0.07°/second pitch, 0.02°/second yaw, and 0°/second roll, indicating smooth separation.

CENTAUR

The observed ignition transient was the smallest recorded to date (see Fig. 12-4), indicating small differential thrust build-up of the RL10 engines. Observed rates were 0.38°/second yaw, 1.02°/second pitch, and 1.17°/second roll. Centaur powered history was smooth and no significant oscillations occurred during the remainder of the flight. From the Centaur rate gyros, frequency data was obtained and plotted with predicted frequencies versus flight time. Figure 12-5 shows the good correlations between the predicted and flight test data.

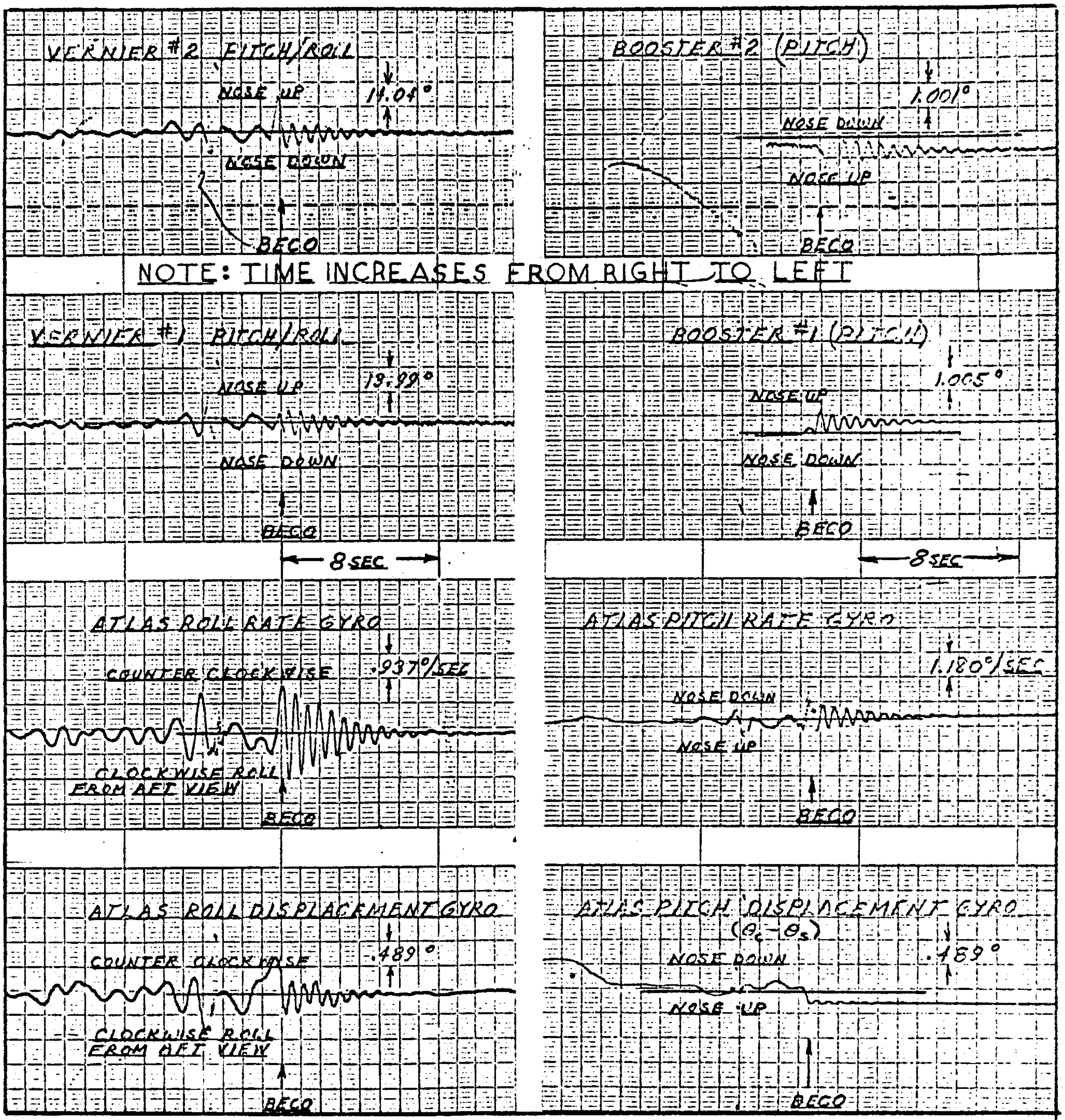
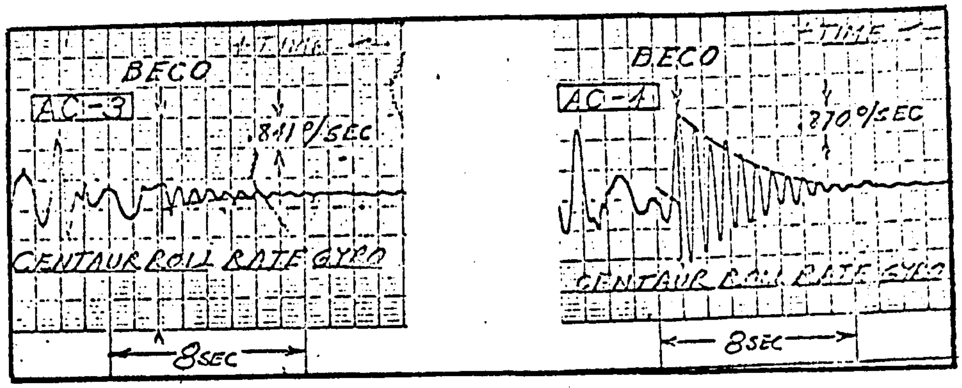


Fig 12-1 AC-4 RESPONSES AT BECO FIGURE 12-1



COMPARISON OF AC-3 & AC-4 ROLL RATES AT BECO

FIGURE 12-2

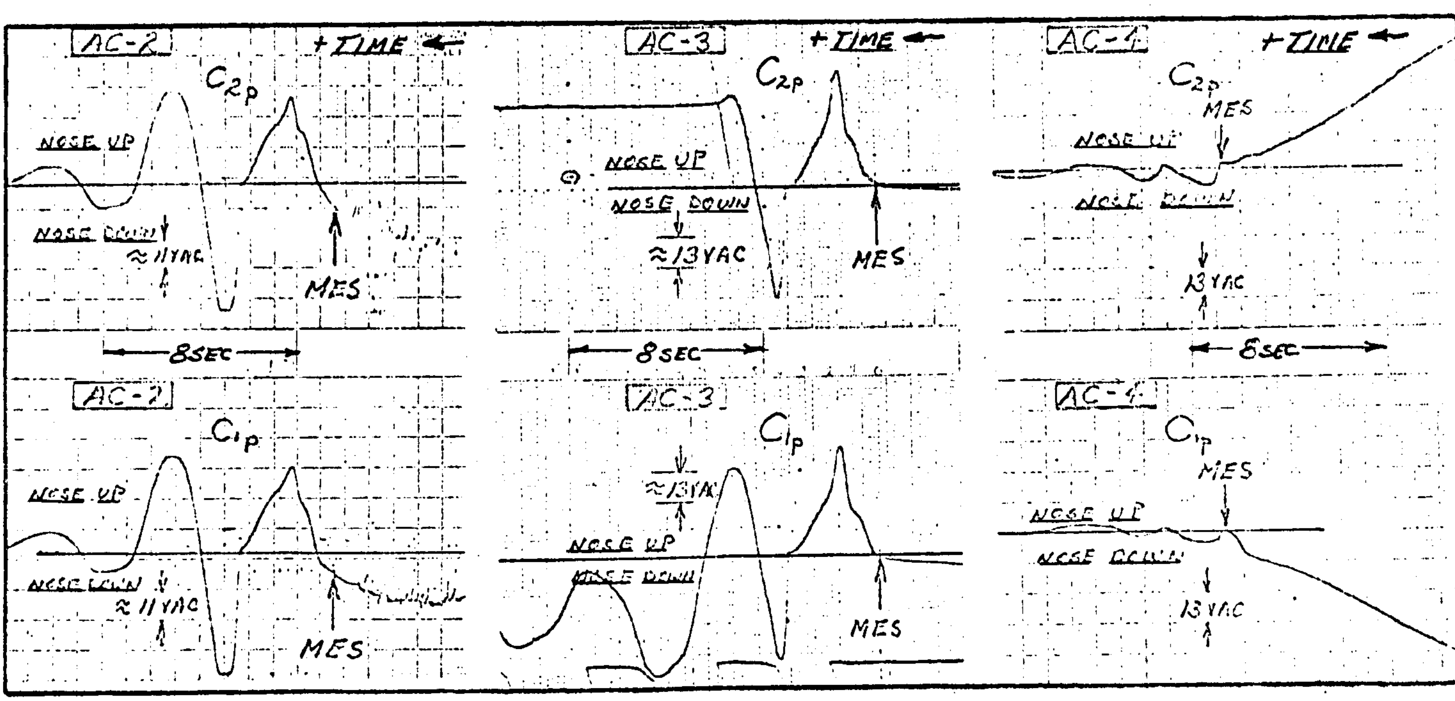
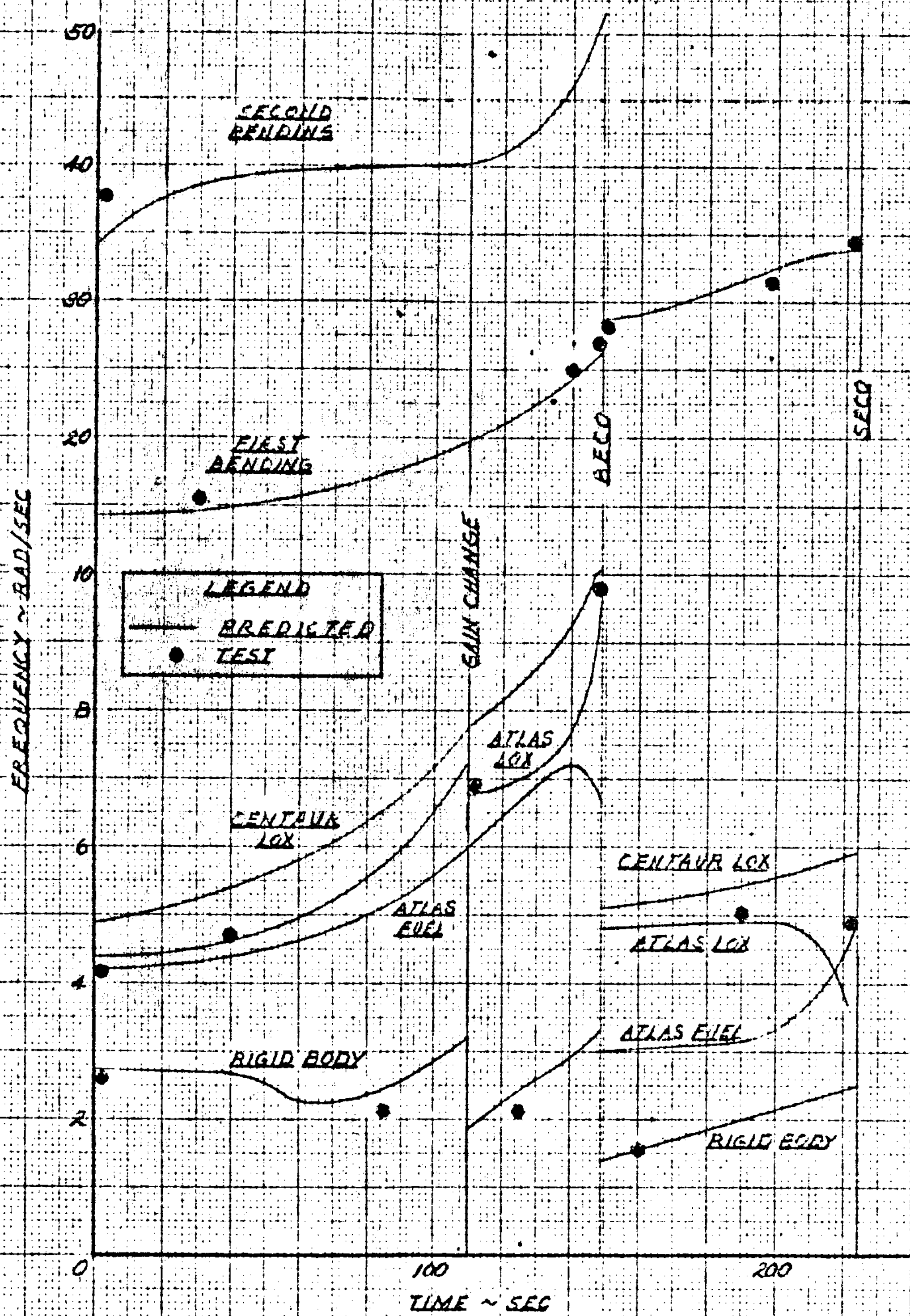


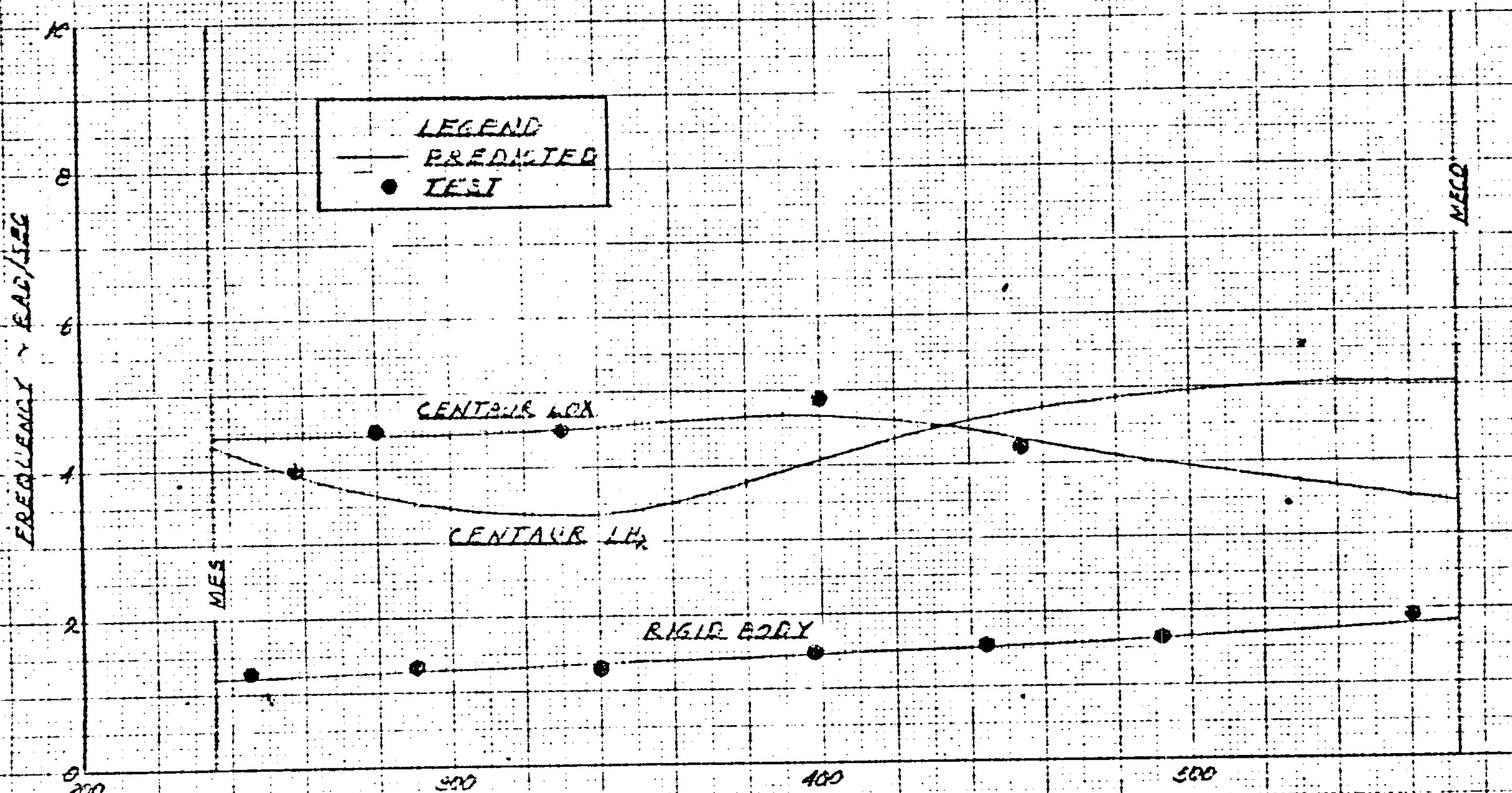
Fig 12-3 COMPARISON OF CENTAUR PITCH ENGINE DEFLECTIONS AT MES

FIGURE 12-3



12-4 AC-4 Predicted and Flight Test Frequencies During Atlas Powered Flight

FIGURE 12-4



12-5 AC-4 PREDICTED AND FLIGHT TEST FREQUENCIES DURING CENTAUR POWERED FLIGHT

FIGURE 12-5

SECTION 13. ELECTRICAL SYSTEMS

SUMMARY

The airborne electrical systems provide onboard electrical power storage, conversion, distribution, and protection, as well as fulfilling the requirement of instrumentation, telemetry, tracking, and range safety command systems. The electrical power system adequately supported the flight, with all redline measurements within the specified limits, and all other measurements at the expected levels. The telemetry and range safety systems experienced no malfunctions during the flight. The instrumentation exhibited reliability typical of such systems, with 95.6 percent of the planned measurements yielding valid data. Performance of the tracking systems was nominal.

ELECTRICAL POWER SYSTEMS BOOSTER MAIN BATTERY AND INVERTER

The Atlas battery voltage at the preflight load test was 29.3 at T + 10 seconds and increased to 30.2 volts at T + 400 seconds with momentary 0.5 volt dips at pyrotechnic firing. Inverter frequency was 402.1 cps at liftoff to 402.5 cps at SECO. Phase voltages remained fairly constant at 114.8 to 115.1 volts, corrected values. Main load current was 62 amperes. Staging disconnect receptable temperature was 32.4° F at liftoff and 8° F at separation.

CENTAUR MAIN BATTERY AND INVERTER

The main missile battery voltage was 28.4 at liftoff, had dropped 0.6 volt at T + 240 seconds and then returned to its original value at T + 800. During the flight, the internal battery temperature rose normally from

102° F (T - 0) to 124° F at T + 800.

The inverter output frequency remained essentially constant at 400 cps throughout the flight, with phase voltages that varied less than 0.6 volts. The inverter case temperature rose from 83° F at liftoff to 150° F at T + 800.

During the countdown, the Centaur power changeover switch exhibited a momentary malfunction. The reason has not yet been established. Atlas wire number W185A20 developed a short circuit, and was removed prior to flight. A spare wire was used in its place. A temporarily poor contact occurred in a Destructor Simulator Fuse clip during RSC checkout. It was repaired.

INSTRUMENTATION AND RF SYSTEMS

SUMMARY

A. Telemetry/Instrumentation

The operation of the Atlas/Centaur telemetry/instrumentation system was satisfactory. Data has been evaluated through T + 1100 seconds. Data quality was generally good with the exception of channel 11 on Atlas RF number 1 and channel C on Atlas RF number 2 which were noisy. Eight measurements failed to yield data and 20 experienced various anamalies or failed during flight. Nine other measurements were deleted prior to flight.

B. Tracking

C-band tracking of the interstage and upper stage transponders was satisfactory during launch phase and continued for approximately 9 hours.

Azusa/Glotrac tracking of the Centaur/Azusa type C transponder was satisfactory with multistation coverage throughout the entire Atlas/Centaur powered flight. In addition Glotrac Segment IV in South Africa acquired and tracked for approximately 50 seconds.

C. Range Safety

The range safety systems on the Atlas and Centaur maintained capability of disabling and destroying the vehicles if required. The Centaur range safety system was in-flight disabled by command at T + 601.5 seconds.

TELEMETRY AND INSTRUMENTATION

For AC-4 four VHF telemetry links were carried on the Centaur stage.

RF 1	225.7 microns, 4 watts power
RF 2	235.0 microns, 4 watts power
RF 3	243.8 microns, 4 watts power
RF 4	251.5 microns, 4 watts power

Two VHF links were carried on the Atlas booster.

RF 1	229.9 microns, 3.5 watts power
RF 2	232.4 microns, 3 watts power

Telemetry coverage from the ETR stations are shown in Figure 13-1. Continuous coverage was obtained from T - 420 seconds to T + 3030 seconds with the exception of 91 seconds from T + 1101 to T + 1192. The following ETR stations supported the test.

Station 1 - Telemetry II at Cape Kennedy

Station 3 - Grand Bahama Island

Station 7 - San Salvador Island

Station 91 - Antigua Island

Lima - Timber Hitch (ship located approximately 14.6° north latitude - 42.7° west longitude)

Station 12 - Ascension Island

Whiskey - Coastal Crusader (ship located approximately 19.0° south latitude - 10.0° east longitude)

Station 13 - Pretoria

Yankee - Sword Knot (ship located approximately 29.0° south latitude - 53.0° east longitude)

Uniform - Twin Falls (ship located approximately 31.0° south latitude - 78.0° east longitude)

In addition to the coverage by ETR the four Centaur telemetry links were recorded by the following stations of the Manned Space Flight Network:

STATION	COVERAGE DURING FOLLOWING REVOLUTIONS
1. Cape Kennedy	1 and 2
2. Grand Bahama Island	1 and 2
3. Grand Turk Island	1 and 2
4. Bermuda	1 only
5. Antigua	1 and 2
6. Timber Hitch (ship)	1 only
7. Ascension	1 only
8. Coastal Crusader (ship)	1 only
9. Pretoria	1 only
10. Tananarive	1,2,3,4, and 5
11. Sword Knot (ship)	1 only
12. Twin Falls Victory (ship)	1 only
13. Carnarvon	1 and 2
14. Hawaii	1,2,3, and 4
15. Saint Nicolas	1,2,3, and 4
16. California	1 and 2
17. Guaymas	1,2, and 3
18. White Sands	1 only
19. Texas	1 and 2
20. Eglin	1 and 2

The four Centaur links were in operation for a total of 6 hours and 45 minutes. Acquisition was lost on the fifth revolution between Tananarive and Hawaii.

The number and type of measurements planned for AC-4 by airborne system are shown in Figure 13-4. Ten measurements of telemetry systems parameters were made on AC-4. All yielded valid data. Temperatures of the four telepaks were normal varying between 53° and 75° F during the time for which data was available (T + 1100 sec). Telemetry battery current was 20 amperes as expected, and decreased to 18 amperes when insulation panels and nose fairings were jettisoned and decreased transducer load.

Multiplexer temperature variation was normal (45° to 75° F). Thermocouple reference junction temperature varied from 29° to 40° F; rate of change was slow (0.5°F/min). C-1 forward instrumentation box and C-2 rear instrumentation box minimum temperatures were 10° and -10° F, respectively. During Centaur burn, these temperature levels were expected and are 20° to 30° warmer than on AC-3. Aft instrumentation box temperature dropped from 55° F at T - 0 to 50° F at first MES and stabilized at 45° F, well within transducer design limits.

The following measurements were deleted prior to flight. None were easily accessible for repair prior to flight:

CA744S	Tank Strain	Station 225
CA757S	Tank Strain	Station 402
CA759S	Tank Strain	Station 402
CA408T	Outer Nose	Station 72
CA857T	Aft Bulkhead Skin	
CA866T	Aft Bulkhead Skin	
AA176S	Strain at Station 582	
AA919T	Temperature at Station 575	
AA925T	Temperature at Station 614	

The following AC-4 measurements yielded no data:

CA2650	LH_2 Boiloff Valve Accelerometer
	Failed to respond during LH_2 vent
CA310	C-1 Gimbal Mount Z-Axis Vibration
	Excessive noise peak to peak
CA451P	Nose Fairing Delta Pressure
	Read zero prior to and throughout flight
CH152T	C-1 Hydraulic Insulation Adapter
	Off-scale low prior to launch and throughout flight
CH153T	C-2 Hydraulic Insulation Adapter
	Off-scale low prior to launch and throughout flight
CM810V	Air Force CRL Spectrometer
	No output received; not functioning properly prior to liftoff
CU12X	LOX Level Station 433.55
	Indicated dry condition at nose fairing jettison until T + 860 second when it again read wet
AS338X	Insulation Panel Jettison Command
	Discrete signal not evident on telemetry

The following measurements yielded data until insulation panel jettison. At that time apparent wiring damage or detachment from tank skin caused each to go off scale.

CA540T	Tank Skin Temperature Station 310
CA758S	Tank Strain Station 402
CA826S	Ring Strain Station 408
CA830S	Ring Strain Station 408
CA832S	Ring Strain Station 408
CA609T	Tank Skin Temperature Station 248

Two temperature measurements failed during flight. Measurement CA537T (tank skin temperature Station 302) operated normally until T 50 seconds at which time the trace went off scale low indicating an open in instrumentation wiring. CP29T (LH_2 boost pump turbine nozzle box temperature) went off scale low at T 610. Valid data was obtained until that time.

Measurement CP28P (LH_2 boost pump turbine inlet pressure) displayed excessive time delay, due to potentiometer contamination of wiper linkage. CP28P indicates pressure rise at T 219 when actual rise took place at T 210.

Traces of the following measurements indicated inadequate thermal bonds to propellant pumps:

CP123T	C-2 engine fuel pump temperature
CP125T	C-2 engine LOX pump temperature

CP123T was erratic prior to and during MES. CP125T required 50 seconds to indicate the 100° drop in temperature at MES while the similar measurement on the C-1 engine showed a similar drop in less than 10 seconds.

The following temperature measurements indicated increased temperatures at insulation panel jettison probably due to varying degrees of bonding failure: It appears that these measurements may yield erroneous data after panel jettison and will be further investigated.

CA543T	Tank Skin S318
CA544T	Tank Skin S320
CA546T	Tank Skin S326
CA547T	Tank Skin S328
CA549T	Tank Skin S334

CA551T	Tank Skin S338
CA707T	LH_2 Sump S387
CA495T	LH_2 Sump S393

Tracking Coverage

ETR radar coverage is summarized in Figure 13-2. In addition to the ETR coverage, radar track was obtained from the Manned Space Flight Network from various stations up to 9 hours and 15 minutes after launch. No observations have been reported from the SAO Network or the Stadan Optical sites. It was estimated that the vehicle burned up during reentry over the South Pacific Ocean at 12:05:30 Zulu on December 12, 1964.

Azusa and Glotrac tracking is summarized in Figure 13-3.

The AC-4 Flight Plan and Data Coverage are indicated in Figures 13-5 and 13-6.

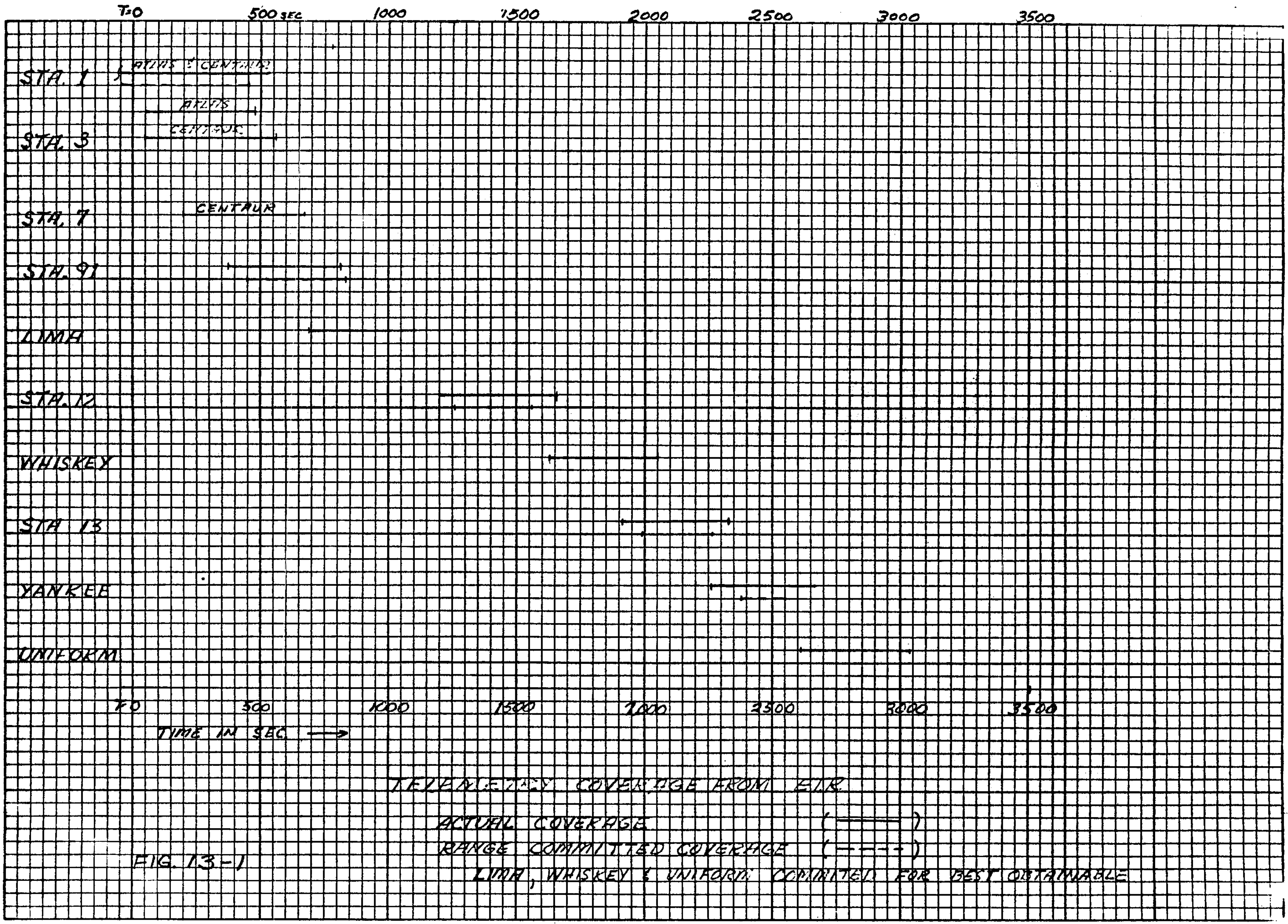

T=0
500 SEC
1000
1500
2000
2500
3000
3500
STA. 1
ATLAS & CENTAUR
ATLAS
CENTAUR
STA. 3
STA. 7
CENTAUR
STA. 91
LIMA
STA. 12
WHISKEY
STA 13
YANKEE
UNIFORM
T-0
500
1000
1500
2000
2500
3000
3500
TIME IN SEC
TELEMETRY COVERAGE FROM ETR
ACTUAL COVERAGE
RANGE COMMITTED COVERAGE
LIMA, WHISKEY & UNIFORM COMMITTED FOR BEST OBTAINABLE

FIG. 13-1

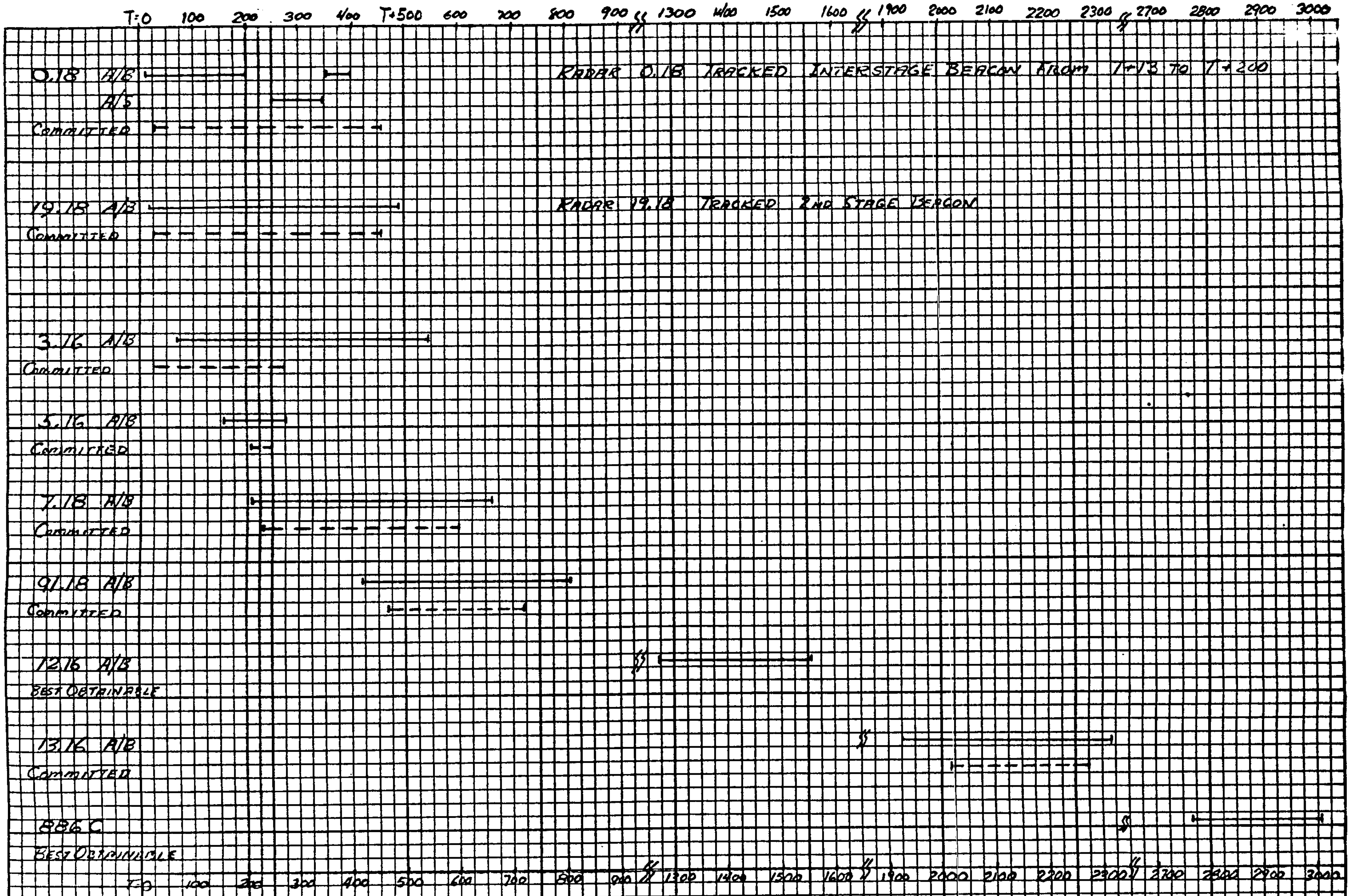


FIG. 13-2 RADAR COVERAGE INTERVALS

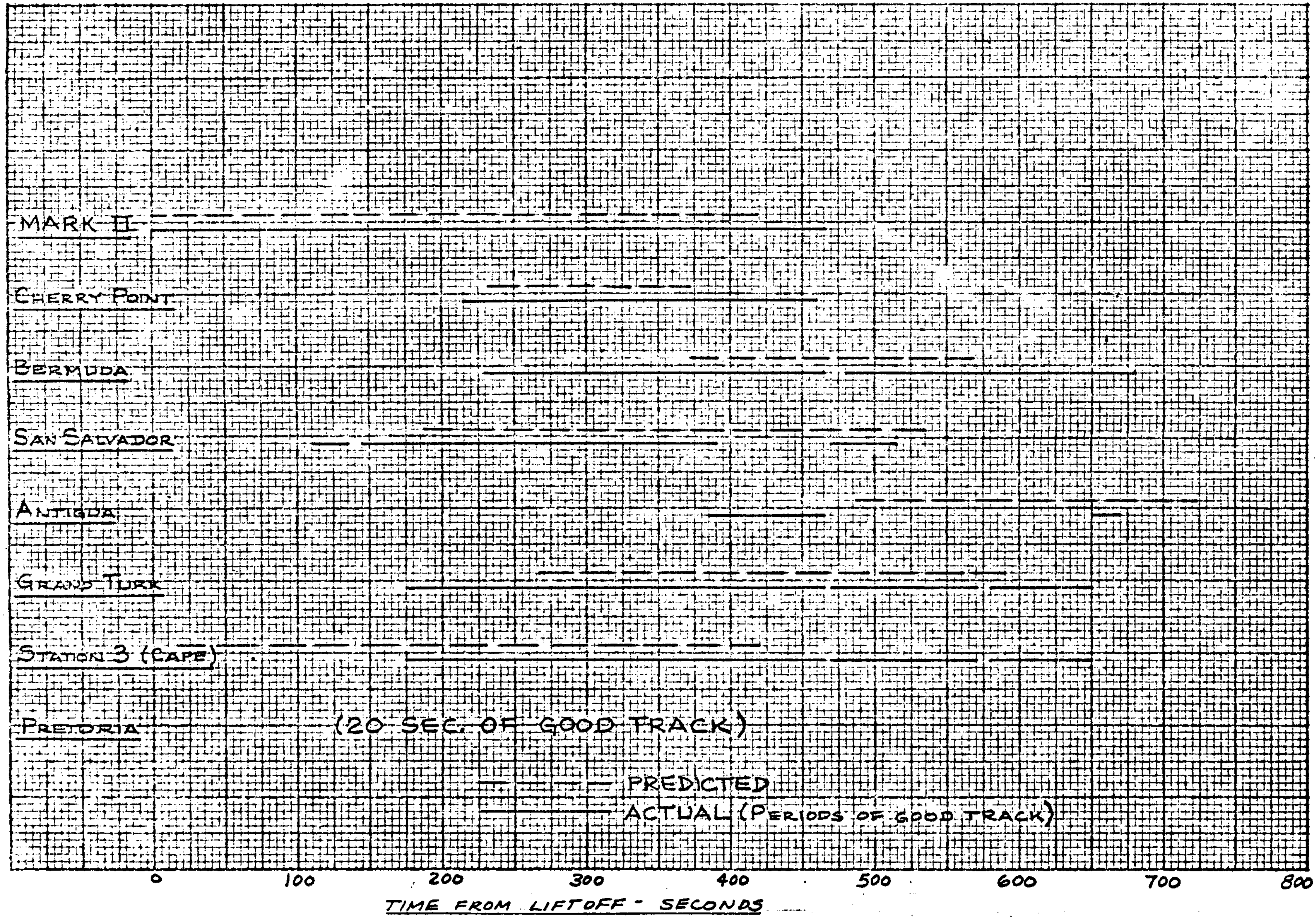


FIG 13-3

AZUSA - GLOTRACK COVERAGE

CENTAUR

ATLAS

VEHICLE SYSTEM	ACCELERATION	ROTATION RATE	CURRENT	DEFLECTION	POWER	LIGHT INTENSITY	VIBRATION	PRESSURE	FREQUENCY	RATE	STRAIN	TEMPERATURE	VOLTAGE	DISCRETE POS.	ACOUSTIC	DIGITAL	TOTAL
AIRFRAME	2 / 4			/ 1		/ 1	10 / 13	22 / 6			17 / 12	150 / 29		1 / 4			202 / 70
C-BAND BEACON										1 /							1 / -
RANGE SAFETY COMMAND													2 / 1	3 / 1			5 / 2
ELECTRICAL			4 /						1 / 1			5 / 1	4 / 2	/ 2			14 / 6
PNEUMATIC								9 / 7				5 / 2		2 /			16 / 9
HYDRAULIC							3 /	4 / 6				12 /					19 / 6
GUIDANCE	3 /											6 /	19 /	4 /		1 /	33 / -
PROPULSION		4 / 3		/ 2			1 /	20 / 19				37 / 2		16 /			78 / 33
FLIGHT CONTROL				/ 13						6 / 3		2 /	8 /	26 / 7			42 / 23
TELEMETRY			1 /									10 / 1					11 / 1
PROPELLANT LEVEL CONTROL								/ 2					/ 1	2 / 7			2 / 3
AZUSA					2 /							1 /					3 / -
PAYLOAD							4 /	3 /				8 /					15 / -
MISCELLANEOUS	3 / 1			5 / 1								5 /	1 /	/ 26	1 /		15 / 28
TOTAL	8 / 5	4 / 3	5 / -	5 / 17	2 / -	- / 1	18 / 13	58 / 40	1 / 1	7 / 3	17 / 12	241 / 35	34 / 4	54 / 47	1 /	1 /	455 / 181

FIG. 13-4

AC-4 MEASUREMENT SUMMARY

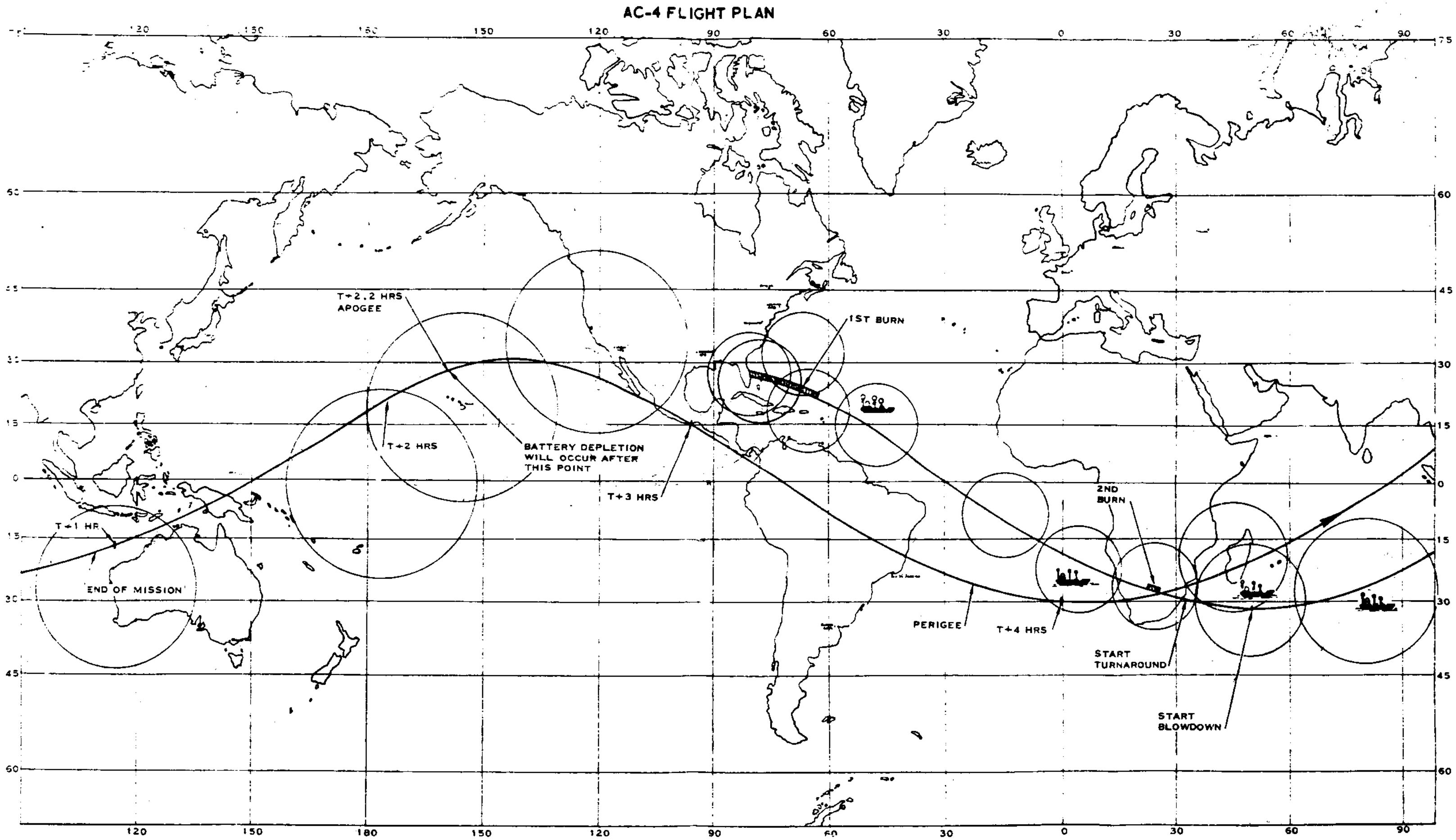


FIG. 13-5 AC-4 FLIGHT PLAN

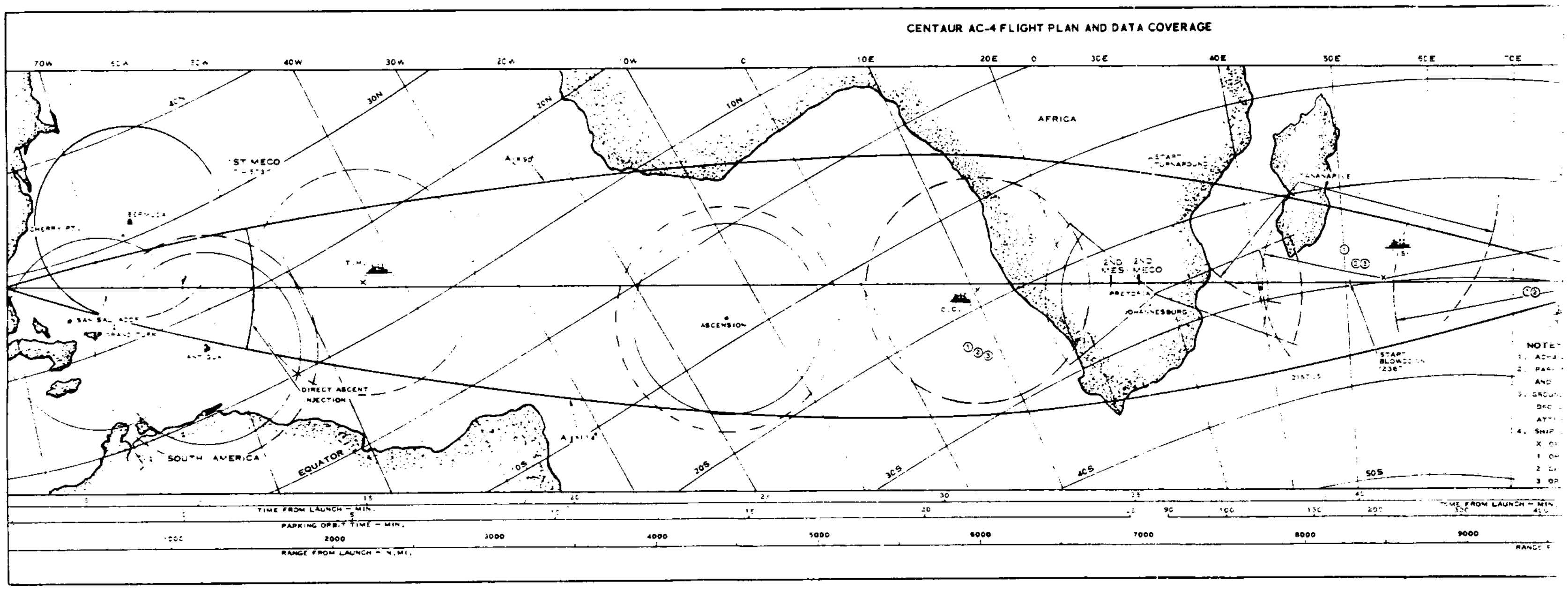


FIG. 13-6 CENTAUR AC-4 FLIGHT PLAN AND DATA COVERAGE

APPENDIX A

ATLAS 146D (LV-3C) FLIGHT TEST RESULTS

The Atlas booster with Centaur second stage and Surveyor payload was launched on December 11, 1964 from complex 36A of the Eastern Test Range, (ETR) at 0925 hours 02.55 seconds EST.

During the countdown the Atlas main missile and telemetry number 1 remotely activated batteries were replaced due to low open circuit voltages. All other Atlas subsystems functioned satisfactorily.

At lift-off and during the booster phase of flight, all Atlas systems functioned satisfactorily obtaining the desired flight trajectory. Minor Atlas functional deviations indicated in the P/U system, hydraulic system, and flight control system data are covered in the detailed subsystems data evaluation.

The remainder of this report is in two sections. Part 1 is a commentary review of the individual systems performance during flight. Part 2 is a summary of selected data points for significant measurements and events.

<u>Part 1</u>. - Systems performance commentaries (146D) flight control systems. The flight control system was satisfactory in all respects except for an unstable condition just prior to BECO.

Lift-off occurred at 14:25:2.55Z and appeared normal with respect to previous flights of this type. The vehicle rolled 0.74 at a rate of 0.9°/sec at lift-off, but this is not abnormal.

Seven seconds prior to BECO, the pitch rate and roll rate gyros showed a diverging oscillation at a frequency of 1.5 cps. This oscillation continued on until BECO. General Dynamics is conducting a math model evaluation to determine the source of this instability and expects to have an answer in January. The maximum peak-to-peak rate was as follows:

Pitch - 2.34°/sec

Roll - 4.6°/sec

Yaw - negligible

Staging and SECO were smoothly executed with no unusual disturbances noted. The Vernier engines were biased correctly to 46° at the proper time, just after booster separation.

For the Centaur missions, the Atlas displacement gyro put-outs are grounded after BECO and the vehicle attitude is determined by guidance received from the second stage. Therefore, the displacement gyros are useful during the sustainer portion of the flight only to determine the manner in which the vehicle responds to the guidance signals.

Torquer amplifier outputs are not monitored during flight; therefore, it is not possible to determine the correctness of the pitch program, except by trajectory tracking.

Missile Electrical (146D) Commentary

The missile electrical, both d-c and a-c systems, functioned satisfactorily. The inverter (Atlas) was adjusted to 402 cps rather than the usual 400 cps. This adjustment was necessary to eliminate the possibility of intermodulation with the Centaur inverter. The adjustment was well within the tolerance of 406 cps and did not affect the mission.

Due to bad data, the electrical measurements prior to BECO could not be obtained. The measurements after BECO were taken from the GBI data charts.

Propulsion System

The operation of the propulsion system was satisfactory. All vehicle subengines achieved ignition stage, transition stage, and mainstage in the normal manner. Flight and shutdown behavior of each engine was also satisfactory. Section 11 compares inflight telemetry data with design nominal values. No anomolies were noted.

Pneumatic System

Performance of the airborne pneumatic system was satisfactory in that all required tank pressures, and control functions were properly supplied. No anomolies were noted. Section 11 compares inflight telemetry data with regulator design ranges.

Propellant Utilization - Flight Data

The P/U system performance was satisfactory.

1. The P/U fuel valve satisfactorily responded to the EDO signal.

2. The sustainer portion of flight was characterized by an indicated LOX rich condition. This condition has been experienced on recent Atlas flights.

3. The sustainer portion of flight was also characterized by a cyclic EDO signal (roughly 1 cps) which indicates that possible propellant sloshing existed.

4. The P/U valve angle lower limit stop was reached and maintained throughout the sustainer portion of flight which indicates a 15 percent fuel lean LOX rich mixture ratio condition existed.

Range Safety Command System

Performance of the Range Safety Command (RSC) was satisfactory. Signal strength at RSC number 1 receiver as indicated by receiver number 1 AGC voltage measurement (D7V) was adequate to provide command capability throughout the powered phase of flight.

Azusa

Signal strength as received by the A/B receiver per measurement Z3E was maintained at a high level throughout powered flight. The minimum level experienced was 58.9 dbm which is well above the threshold level of 110 dbm.

Telemetry

Signal strength data is not available; however, it can be considered satisfactory since none of the telemetry station's decommutators lost lock. All commutator repetition rates and subcarrier oscillator frequency deviations were within tolerance. All inflight calibrations on continuous channels were within specifications indicating that the respective SCO's were also within specification limits.

Hydraulic System

Hydraulic system performance was satisfactory. Some of the data recorded is suspect due to recording or telemetry problems (ref. Section 11).

FLIGHT CONTROL SYSTEM

Flight Data Time/Event Summary

Event	GMT Z	Sec
Lift-off	14-25 - 2.55	0
MAX Q	Approx. 14-26--32.50	+90
BECO	14-27 - 31.65	+149.1
Booster Jettison	14-27 - 34.30	+151.75
SECO/VECO	14-28 - 46.85	+224.3
Atlas/Centaur Separation	14-28 - 49.25	+226.7

Roll program, normal.

Pitch program, normal.

Vehicle Altitude and Rates at Specific Events

	Pitch		Yaw		Roll	
	Displacement gyro	Rate gyro	Displacement gyro	Rate gyro	Displacement gyro	Rate gyro
Before BECO After BECO	-0.09° $+0.30^\circ$	-1.17°/sec -0.94°/sec	$+0.5^\circ$ $+1.09^\circ$	Negative Negative	-0.33° $+0.74^\circ$	-2.3°/sec $+0.49^\circ$/sec
Before SECO After SECO	Off scale Off scale	-0.94°/sec -0.94°/sec	$+1.61^\circ$ $+1.61^\circ$	Negative Negative	Negative Negative	Negative Negative
Before Atlas/ Centaur separation	Off scale	-0.94°/sec	$+1.61^\circ$	Negative	Negative	Negative
At Atlas/ Centaur separation	Off scale	-0.94°/sec	$+1.61^\circ$	Negative	Negative	Negative

Missile Electric System Flight Data

	T-50	Transfer	Lift-off	BECO	SECO/ VECO	Booster separation, shroud separation	Atlas/ Centaur separation
1. Vehicle d-c Bus VDC	No data available	No data available	No data available	31.4	31.4	31.4	31.35
2. Inverter frequency, cps	No data available	No data available	No data available	403.6	403.6	403.6	403.6
3. Phase A Voltage VAC	No data available	No data available	No data available	114.1	114.1	114.1	114.1

Propulsion System Flight Data

Parameter	Design nominal	BECO	SECO	VECO
B-1 chamber pressure, psia	546	547	------	---
B-2 chamber pressure, psia	546	541	------	---
Booster gas generator chamber pressure, psia	475	480	------	---
B-1 pump speed, rpm	6,084	5,950	------	---
B-2 pump speed, rpm	6,060	6,190	------	---
Sustainer chamber pressure, psia	706	679	669	---
Sustainer gas generator discharge pressure, psia	664	648	648	---
Sustainer pump speed, rpm	10,137	10,060	10,160	---
V-1 chamber pressure, pump feed, psia	358	358	354	354
V-2 chamber pressure, pump feed, psia	358	362	358	358

Propellant utilization system telemetered data was recorded from time T-77 sec to T+458 sec. The following P/U measurements were made: P529D H.S. sust. main LOX valve, degree (92.66° to -3.86°); P830D P/U sust. fuel valve, degree (78.80° to -30.80°); U91V error ratio demod. output, VDC (-20.20 to 21.28 VDC/0 to 100 percent IBW calibration).

Propellant Utilization System Flight Data

Measurement	L/O + 10	BECO - 1	BECO + 10	SECO - 1	Nominal
U91V (EDO)	-1	+3	+7	+9	0
P529D (H.S. LOX)	46°	44°	50°	49°	None
P830D (P/U fuel)	22°	20°	20°	21°	*

*Rocketdyne values.
Nominal, 26.7 ± 0.5°.
Upper limit, 37.4 ± 0.5°.
Lower limit, 21.6 ± 0.5°.

Pneumatic System Flight Data

Parameter	Regulator design range, flight	Liftoff	BECO	SECO
LOX tank ullage pressure, psig	28.5 - 31.0	30.3	32.1	32.6
Fuel tank ullage pressure, psig	57.0 - 59.9	59.3	59.4	52.4

Hydraulic system telemetered data was recorded from time -77.0 seconds to +458 seconds. Hydraulic system performance was satisfactory with exceptions noted.* The following hydraulic measurements were made:

Hydraulic System - Flight Data

Measurement	After oil evacuation, psia	Peak pressure prior to liftoff, psia	Liftoff, psia	BECO time, 149.0 seconds, psia	SECO time, 224.2 seconds, psia	VECO time, 224.2 seconds, psia	Nominal liftoff to SECO
H140P	1980	3330	3120	3040	3040	3040	2950 min. 3150 max.
H130P	2000*	3280	3070	3000	3500⊙	3500⊙	2950 min. 3150 max.
H3P	140+	3260	3060	3000	----	----	2950 min. 3150 max.
H33P	1980	3320	3050	3050	----	----	2950 min. 3150 max.
H601P	83	83	83	83	83	83	65 min. 78 max.
H224P	74	74	74	74	----	----	65 min. 78 max.

H140P Sustainer/Vernier hyd. pressure (Calibration 0 to 3546.0 psi).
H130P Sustainer hyd. pump discharge (Calibration 3 to 3566 psi).
H3P Booster hyd. pump discharge (Calibration -6 to 3551 psi).
H33P B_1 Engine hyd. accumulator (Calibration 4 to 3553 psi).
H601P Sustainer hyd. return line (Calibration -2.9 to 609.6 psi).
H224P Booster hyd. system return pressure (Calibration 1.2 to 610.2 psi).

*In general the data is suspect to recording or telemetry problems.

Remarks:

H140 - Decayed abruptly after SECO to 285 psia in approximately 4.8 seconds. (Normal Agena accumulator bottoms out at approximately 900 psia.)

H130 - *This measurement should be "0" at this time.

⊙Rerun shows these readings to be normal after booster separation at 3000 psia. First run would indicate instrument malfunction.

H3P - +This measurement should be "0". Indicates instrument malfunction.

H33P - Trace of this measurement very ragged but typical of this transducer.

H601 - Measurement 5 psia over nominal.

RSC Flight Data

RSC Number 1 Received AGC Quantitative Readouts

Time	Reading
Liftoff	188.2μ volts
BECO	188.2μ volts
SECO	158.8μ volts
Atlas Agena Separation	158.8μ volts

All of the above readouts are well above the 5μ volt threshold level.

Azusa Flight Data

Azusa CF3E X ponder (RF input/AGC) Quantitative readouts

Time	Reading
Liftoff	-50 DBM
BECO	-50 DBM
SECO	-54.4 DBM
Atlas-Centaur Separation	-58.9 DBM

All of the above readouts are well above the -110 DBM threshold level.

APPENDIX B

ABBREVIATIONS

AC	Atlas Centaur
a.c.	alternating current
A. G. C.	automatic gain control
Al	aluminum
ANT.	Antigua
ANT.	antenna
AOS	acquisition of signal
A/P	autopilot
BECO	booster engine cutoff
BET	best estimate of trajectory
BPS	boost pump start
CAPE	Cape Kennedy
cg	center of gravity
DA	double amplitude
dbm	decibels above 1 milliwatt
EST	eastern standard time
ETR	eastern test range
F-	refers to days prior to launch day
F+	refers to days after launch day
gal	U.S. gallon
GBI	Grand Bahama Island
GD/A	General Dynamics - Astronautics
G. G.	gas generator

GLOTRACK	global tracking
GMT	Greenwich mean time
GN_2	gaseous nitrogen
H_2O_2	hydrogen peroxide
He	helium
IAT	initial acceptance test
IGS	inertial guidance system
LH_2	liquid hydrogen
LHe	liquid helium
LOS	loss of signal
LOX	liquid oxygen
ma	milliamps
Mc	megacycles
MECO	main engine cutoff
MES	main engine start
MS	mean square
mw	milliwatts
noz	nozzle box
NPSH	net positive suction head
NPSP	net positive suction pressure
OSH	off scale high
PAFB	Patrick Air Force Base
PCA	point of closest approach
PETN	type of explosive
psia	pounds per square inch absolute

P/S	prestart
psi	pounds per square inch
p-p	peak to peak
PSD	power spectral density
PU	propellant utilization
Q	quadrant
QUAD	quadrant
RCVR	receiver
RF	radio frequency
rms	root mean square
rpm	revolutions per minute
S.A.	single amplitude
SANSAL	San Salvadore
SAO	Smithsonian Astronomical Observatory
SCF	standard cubic feet
SECO	sustainer engine cutoff
SLV	Space Launch Vehicle
S/N	signal to noise ratio
Sta	station
STL	Space Technology Laboratories
TCA	temperature control amplifiers
Tel	Telemetry
T-	refers to time prior to launch (2 in. motion)
T+	refers to time after launch (2 in. motion)
TRW	Thompson Ramo Wooldridge
VECO	Vernier engine cutoff
VAC	volts a.c.